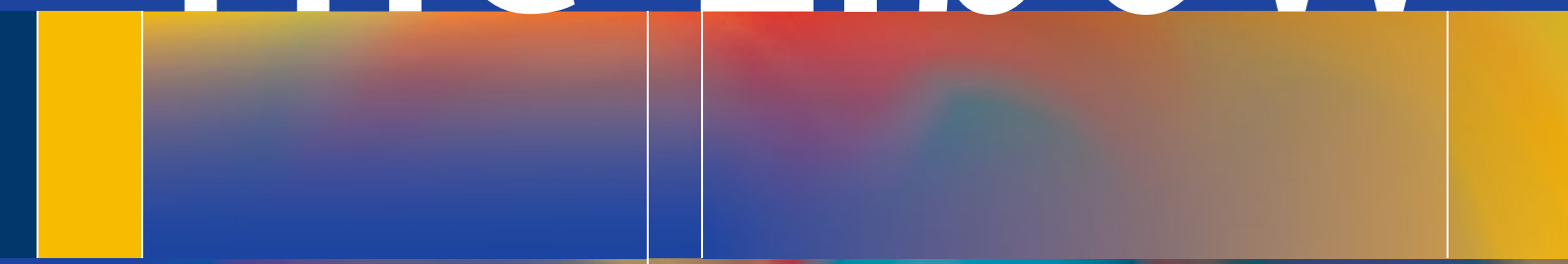
Giuseppe Porcellini
Roberto Rotini
Susanna Stignani Kantar
Silvia Di Giacomo
Editors

The Elbow

Principles of Surgical Treatment and Rehabilitation



Springer

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To Elisa Geranio.

Foreword

During the last two decades we have witnessed an admirable improvement in our understanding of elbow problems. Correlation of anatomic abnormalities with basic biomechanics has led us into quite sophisticated surgical techniques in both acute trauma and reconstructive surgery. Today we can talk about the development of an "elbow career" and orthopedic surgeons can focus their practice almost exclusively in this joint.

The book Drs. Porcellini, Rotini, Stignani, and Di Giacomo have edited reflects this trend. *The Elbow: Principles of Surgical Treatment and Rehabilitation* covers the whole spectrum of acute and chronic elbow problems, from the initial work up to the final therapeutic decision, either conservative or surgical. A unique aspect of the book is its special emphasis on rehabilitation after injury or after surgical treatment. This is very rarely covered in other monographies devoted to the elbow. The information is extremely very well structured, it reads easy, and the figures included illustrate the most important aspects of each chapter.

The tremendous amount of time and dedication put in this text is the logical consequence of many years of scientific and clinical work done by the editors. They have indeed contributed to place Italy among the leader countries in elbow research around the world. The wise decision of sharing and writing their experience and knowledge in English will make this volume a great value to any orthopedic surgeon, physiotherapist, or sports medicine specialist with interest in the elbow. Both residents and more experienced physicians will find it very useful to solve their doubts and to improve their technique. This book should be undoubtedly in the library of any orthopedic department. I commend the editors and all authors for a "delicious" piece of work.

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Preface

Surgery of the elbow and postoperative rehabilitation techniques have shown considerable development in recent years, thanks to the interest of dedicated specialists.

Elbow trauma, whether occurring during work or sporting activities, can cause permanent disabilities that are very challenging to treat subsequently. This prompted us to present this volume, with its overview of the state of the art in the treatment of elbow disorders, resulting from the effort and enthusiasm of friends and colleagues sharing the same passion for this joint.

Coming from the Rizzoli Orthopaedic Institute, we have introduced the book with a chapter on the history of elbow surgery, which finds its roots in this Institute, thanks to the experience of masters such as Alessandro Codivilla, Vittorio Putti, and especially Francesco Delitala, who can legitimately be considered one of the founding fathers of modern elbow surgery.

In this volume there is room for most trending topics, examined and discussed from the points of view of both the orthopedic surgeon and professionals in the rehabilitation field, the latter being of growing importance for achieving good functional outcomes. As well as chapters devoted to traditional basic science, surgical techniques, and aspects of rehabilitation, we have also included chapters on the pathology of elbow injuries in specific sporting activities.

We thank our collaborators, who daily support us in the complex and exciting procedure of caring for patients, and we hope this text can be a useful and reader-friendly tool for those professionals who, on a daily basis or less frequently, treat patients with elbow disorders.

Enjoy your reading!

Modena, Italy — Giuseppe Porcellini
Bologna, Italy — Roberto Rotini
Bologna, Italy — Susanna Stignani Kantar
Forlì, Italy — Silvia Di Giacomo

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Part I

General Principles and Diagnostic Management

History of Elbow Diseases at Rizzoli Orthopaedic Institute

1

Roberto Rotini, Maurizio Fontana, Marco Cavallo, and Alice Ritali

1.1 Introduction

The Rizzoli Orthopaedic Institute, considered to be one of the oldest orthopedic centers in the world, this year celebrates 120 years of service. The reason why this book is introduced with a study about the historical roots of elbow disease at Rizzoli is because most of its authors started their careers in orthopedics at this institute. Besides that, it is very interesting to see how knowledge evolved over more than 100 years in Bologna from its early pioneers to the avant-garde orthopedic surgery throughout the world, especially elbow surgery, which had been neglected for decades.

In the second half of the nineteenth century, surgery underwent a radical change, which was mainly due to three major discoveries.

Lister (1827–1912) started to use carbolic acid to disinfect wounds, which lay the foundations for systematic sterilization in surgery. "The surgeon finally had the means to get at joints and cavities without the danger that infection would decimate the patients" (Delitala, COM 1950).

Horace Wells with nitrous oxide (1845) and William Morton with sulfuric ether (1846) introduced the initial concepts of sedation, thus giving rise to anesthesia, a huge leap forward, which enabled longer and more complex operations to be performed.

In 1896, Wilhelm Conrad Roentgen showed Würzburg the first radiograph, which was performed on the hand of his colleague, the anatomist Koellinker. This discovery, which finally allowed the anatomy of the skeleton to be seen, drastically changed the diagnosis and treatment of musculoskeletal diseases; the science of orthopedics had started to break away from the field of general surgery and slowly began to constitute a discipline in itself.

Between the nineteenth and twentieth centuries, this was the foundation for the first centers entirely dedicated to orthopedic surgery: in Milan under Pietro Panzeri and then Riccardo Galeazzi, in Bologna under Alessandro Codivilla and then Vittorio Putti, in Turin under Fedele Margari, in Pisa under Agostino Paci, subsequently in Rome under Riccardo Dalla Vedova, in Naples under Luigi De Gaetano, and in Florence under Piero Palagi.

1.2 History of the Rizzoli Orthopaedic Institute

The institute is situated in the monumental complex of San Michele in Bosco. Originally a convent that was built in 1437 by Olivetan monks, it has charmed numerous visitors throughout the centuries including popes, cardinals, monarchs, and leaders such as Napoleon Bonaparte. Because of its awesomeness and position on the hills overlooking the city, it is one of the main monastic complexes in Italy. In the 1500s, frescoes by Gherardi, also known as il Doceno, and Vasari enhanced San Michele in Bosco, as did the library, which dates back to 1517, where one of the rarest and most complete orthopedic book collections is housed (28,000 volumes) along with Putti's study which contains 17,000 manuscripts, 66 incunabula, and 238 fifteeners.

The Rizzoli Orthopaedic Institute was founded at the end of the nineteenth century by the celebrated Bolognese surgeon and philanthropist Francesco Rizzoli, who bought the convent and the hill of San Michele in Bosco. Making a donation to the Province of Bologna, he realized a public institute specialized in orthopedics.

Opened in 1896 (Fig. 1.1), it would be the first in Italy and among the first in Europe to be actually dedicated to orthopedics from the outset. Before this, other institutes carried out activity mainly dedicated to the treatment of skeletal

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Fig. 1.1 28 June 1896, inauguration of the Rizzoli Orthopaedic Institute attended by the Italian Royal Family. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

deformities connected to rickets. The best example of this was the Rickets Institute set up by Gaetano Pini in 1874 in Milan.

Looking back on Rizzoli's history, you can notice particular "periods" of research into the most common and disabling diseases, which changed over time according to the historical discoveries that were able to combat a particular disease. As already mentioned, the mission of the first generation of institutes was to treat rickets using osteoclasis and plaster casts. With the discovery of vitamins in 1897, the cause of rickets was found, and the way was paved to stopping the most common metabolic bone disease. Tuberculosis and osteomyelitis began to be treated at the beginning of the 1900s by heliotherapy and draining abscess cavities. From 1935–1944 sulfonamide, penicillin, and streptomycin were introduced and radically changed the outcome of war wounds and tuberculosis. Undoubtedly, the first five directors of the Rizzoli Orthopaedic Institute used many of their resources on the surgical treatment of an epidemic that struck young people all over Europe, i.e., poliomyelitis. Osteotomy and tendon transfer filled their books and atlases. The widespread introduction of polio vaccine (Salk and Sabin, 1958) dealt a vital blow to what was the most common secondary cause of disease in the musculoskeletal system. The 1970s saw the advent of chemotherapy cocktails in oncology, which were effective against osteosarcoma, whereas CT and MRI greatly improved diagnostics and helped to increase the treatment success rate and reduce the number of amputations. Progress in new biocompatible materials, such as titanium, polyethylene, acrylic cement, and ceramics, also helped to boost the rate of joint replacement surgery. In 1972 Watanabe introduced the use of optic fiber and video cameras, thus enabling the spread of arthroscopic surgical techniques, starting from the knee and then extending to all the major joints.

Thanks to a fortunate combination of great surgeons and skillful administrators and the close integration of healthcare, constant clinic technical-cultural exchange between surgeons and engineers, and research, the Rizzoli Orthopaedic Institute has remained at the cutting edge of technology. Since 1981 it has been recognized as a Scientific Research Hospital by the Italian Health Department. The research center of the institute boasts 15 labs where programs of basic, translational, and clinical research are carried out covering all physiology sectors of the musculoskeletal system. Since 1997, the institute has also been operating a bank of musculoskeletal tissue.

1.3 The "Greats" of the Rizzoli Orthopaedic Institute and Their Experience with the Elbow

Alessandro Codivilla (1861–1912), who took over from Pietro Panzeri in 1899, was the first director of Clinical Orthopedics and is known worldwide for treating long bone fractures by direct traction on the skeleton using a pin anchored to the calcaneus (Fig. 1.2).

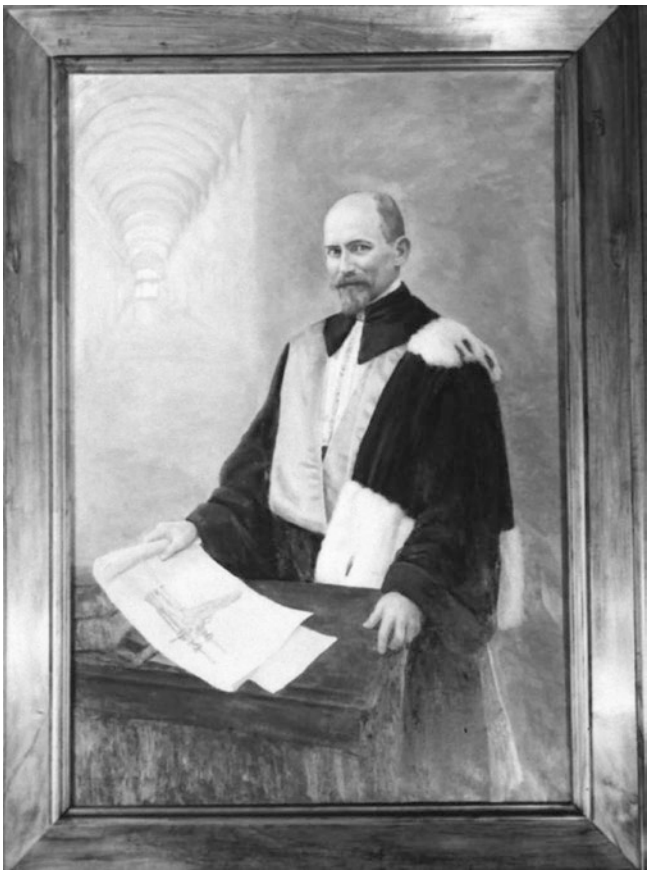


Fig. 1.2 Portrait of Professor A. Codivilla, represented in the main corridor of the historical wing of the Rizzoli Orthopedic Institute. In his hand he holds a scheme of the direct traction on the skeleton. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission



Fig. 1.3 First X-ray performed at Rizzoli Orthopaedic Institute showing an arthritic elbow, 1899. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

He has been acknowledged as the pioneer of congenital clubfoot treatment, besides publishing important papers on tendon transfer, congenital hip dislocation, joint tuberculosis, etc. Under his leadership a photograph archive was started in order to document the patients treated. Three years after Roentgen's discovery, in 1899 the first radiograph was performed on a patient suffering from arthritic elbow (Fig. 1.3).

His pupil and successor to the chair of Bologna was Vittorio Putti (1880–1940), who set up a prestigious school of orthopedics with numerous pupils from Italy and South America. Thanks to his stubborn determination advances were made in all fields of orthopedics, and the Rizzoli Orthopaedic Institute became a comprehensive orthopedic center. In 1914 the Rizzoli Workshop was set up on the hospital grounds, which became an essential part of surgical practice as highlighted by Delitala: "If the surgeon has good mechanical skills, he will find almost instinctively, while operating, the right tools to perform the new techniques and thus he can design new tools better than any mechanic can make. If he has at his disposal an equipped workshop, even better, because the work of a mechanic and craftsman completes that of the surgeon" (page 579, Delitala's notes).

In the same year, he also founded the scientific journal *Chirurgia degli Organi di Movimento (Musculoskeletal Surgery*) and in 1923 set up a heliotherapy center to treat infection and joint tuberculosis in Cortina d'Ampezzo. In 1926 the school of anatomical drawing was established (Director Remo Scoto), which was the only nonmedical hospital service in Europe.

Concerning the elbow, he proposed a novel operation: interposition arthroplasty which involved the use of intra-articular aponeurosis flaps to treat stiffness (orthopedic archive, 1913). The first arthroplasty was performed by Putti precisely in the elbow in 1910, as he stated at the sixth international society meeting in London where he presented his case series of 142 arthroplasties mainly performed on the elbow (Vallardi 1950) (Fig. 1.4).

At that time, there was a lot of doubt about this operation, which was deemed aggressive. "Arthroplasty is one of the most complex and virtuous expressions of the art of surgery" was his reply, after reiterating that "… in most cases arthroplasty is not a necessary but an elective operation and should be proposed after consciously weighing up

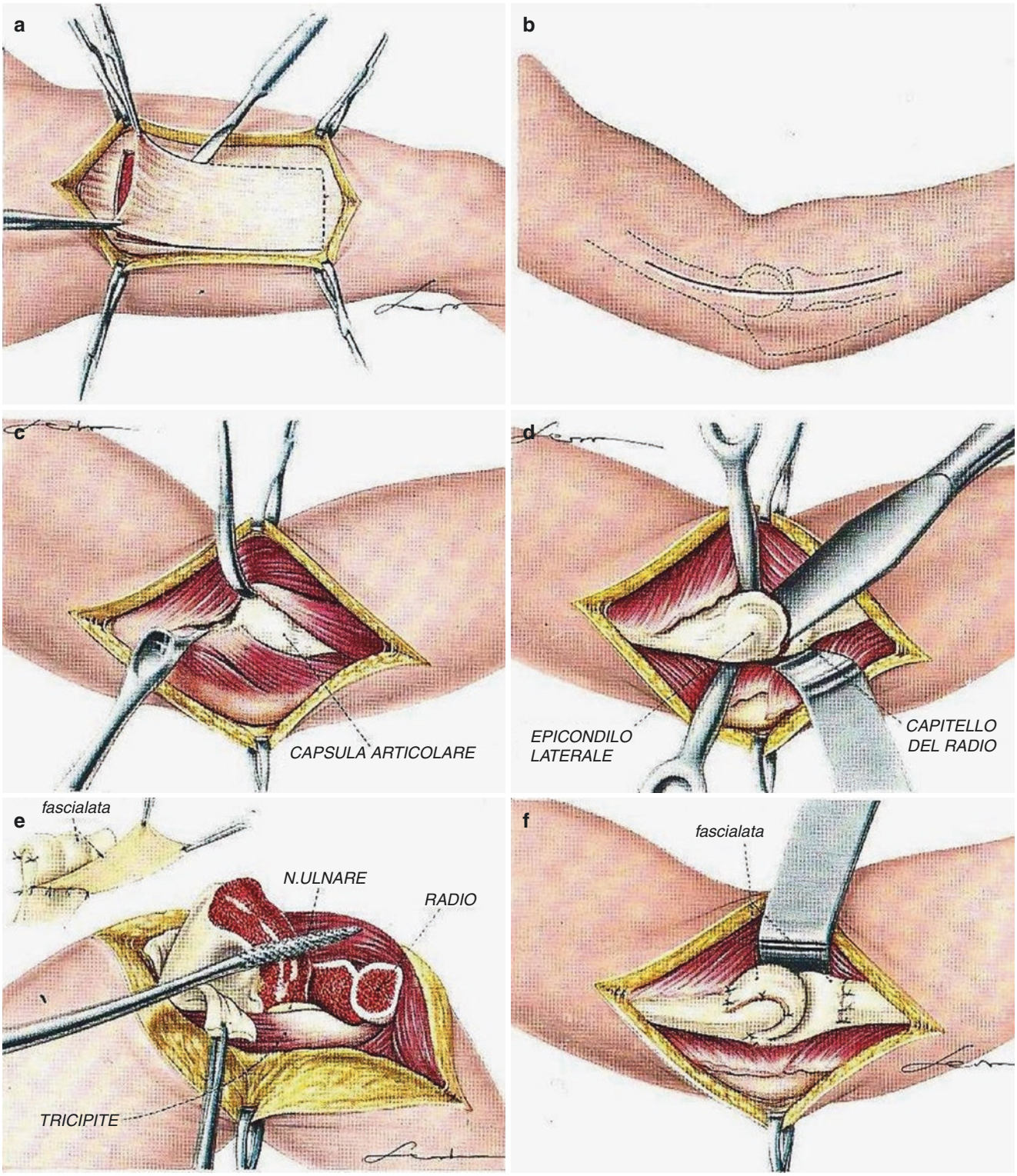


Fig. 1.4 Interpositional arthroplasty of the elbow: surgical technique described by Professor V. Putti, (**a**) harvesting of the fascia lata, (**b**) lateral skin incision of the elbow, (**c**) lateral approach by Kocher, (**d**) preparation of the articular surfaces, (**e**) fascia lata grafting between the joint surfaces, (**f**) final coverage of the ulnar-humeral joint. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

clinical criteria and experience against the likelihood of success or failure … but I will not accept the biased opinion of those who claim that ankylosis is the least of all ills or even a favorable functional condition" (Putti 1952). In conclusion, Putti anticipated the rehabilitation phase (self-managed) by foreseeing a critical period around the 45th day when he recommended persevering with treatment (Fig. 1.5). "The secret of the success of arthroplasty lies nine times out of ten in the functional treatment, because the surgical operation is only the preparatory event, whereas exercise and function are the actual biological factors of the new joint" (Putti 1952) (citation page 857 Putti's notes). Moreover, the original technique of humeral-ulnar fusion with autologous bone graft was developed by his pupil Sanzio Vacchelli.



Fig. 1.5 Professor Putti teaching a patient affected by elbow stiffness self-assisted rehabilitation exercises. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

In 1940 Putti developed several corrective techniques for the most common paralyzing syndromes of poliomyelitis of the upper limb including those called "pronator" and "supinator" syndromes of the forearm, which Zanoli described in his book (Cappelli Editore 1960) (Fig. 1.6).

Putti died suddenly in 1940, and it was Francesco Delitala who stepped into his big shoes (Fig. 1.7). After a difficult organization period during the Second World War when the institute was under German command, in 1946 business as usual was restored at Rizzoli. Together with other pupils, Delitala continued along Putti's course by archiving his master's notes and publishing (together with Roberto De Gennaro) a *Treatise of Orthopedics and Traumatology* (an essential textbook for generations of orthopedic surgeons) where he recorded most of the surgical techniques in use at the time, enhanced by anatomical tables by Remo Scoto, but above all exploring the new chapter of joint replacement surgery. Among the first prosthetic elbow implants, reported in the literature, Delitala's book on endoprostheses cites Mellen and Phalen's (1947) work in 1947 on methyl-methacrylate endoprostheses implanted in four patients with war wounds, which failed due to pain and joint instability. Delitala developed a total hinged metal prosthesis, designed at the IOR workshop, of which we found the documentation from 1948 in our photographic archive, unpublished by the author.

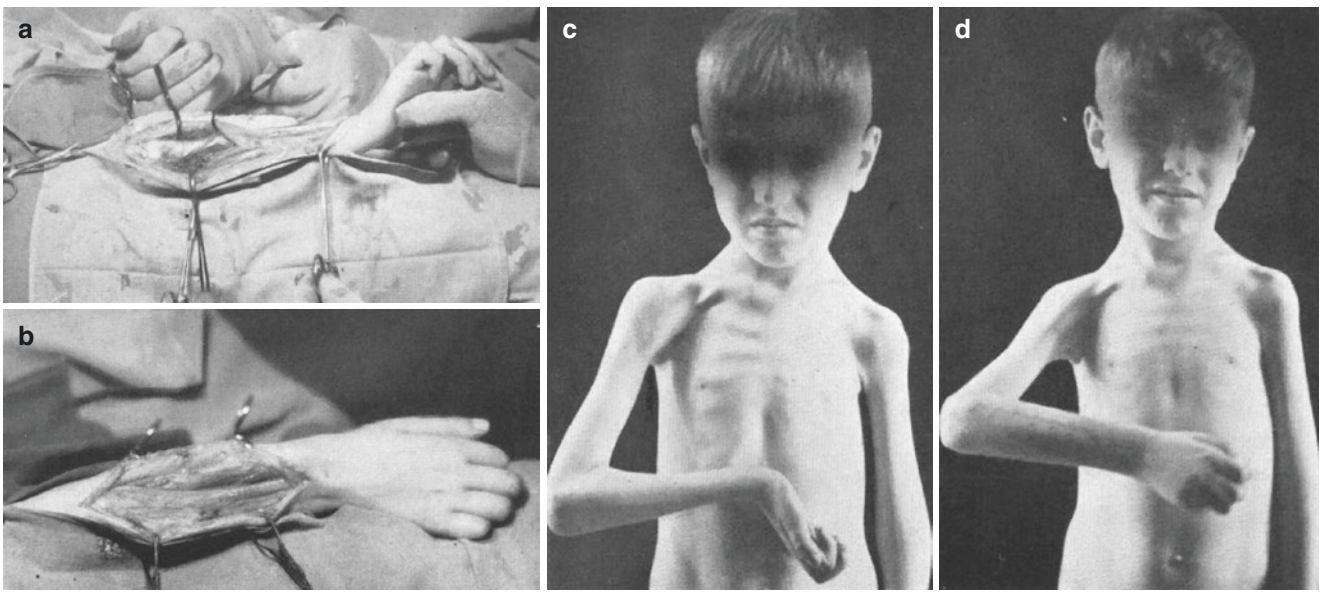


Fig. 1.6 (**a**, **b**) Intraoperative pictures of the radioulnar complex arthrolysis and release of the ulnar insertion of the supinator muscle for supinator syndrome correction without bony procedures. (**c**, **d**) Clinical result after the same surgical procedure of a polio patient affected by supinator syndrome of the right forearm showing a good movement in pronation-supination. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission



Fig. 1.7 Portrait of Professor Francesco Delitala (1883–1983). Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

It was the prosthetic implant of a woman who presented total loss of bone at the elbow as the result of an exploded grenade (Figs. 1.8 and 1.9).

Even if the design is rudimental, by today's biomechanical standards, that case has marked historical value because it can be considered as one of the first total joint replacements to be performed in the world. At the same time, he performed a humeral prosthetic implant to treat posttraumatic stiffness in a 41-year-old patient, already treated by fascia lata arthroplasty, without added benefit (Cappelli Editore 1956) (Fig. 1.10).

Both cases were complicated by infection which required removal of the prosthesis after a few months. After this experience the author underlined "the utmost importance of sterile conditions" (Cappelli Editore 1956). Later, after improving the technique and with the added potential of antibiotics, other types of prosthetic implants were developed by Delitala's pupils for bone tumors. We still have the drawings of these implants designed at the Rizzoli Workshop (until the 1960s the linked and later unlinked types were used and polyethylene and ceramics were introduced) (Fig. 1.11).

Therefore, Delitala can be thought of as one of the European pioneers of joint replacement, especially of the elbow. "… also abroad, especially in the USA, similar developments were taking place simultaneously unbeknownst to each other. When the results of treatment in distant countries, without exchanging ideas, come together, it means that the studies and methods undertaken must be continued." It should also be highlighted that Delitala already understood the importance of the radial head and its replacement in case of fracture nonunion: "Because many cases of simply removing the head heal with good movement, it is questionable whether the EP (of the radial head) is really necessary. There is no doubt that by replacing the femoral head function is better and secondary movement of the radius is avoided" (Cappelli Editore 1956) (Fig. 1.12).

Moreover, "success is achieved only when prostheses are perfect, tailor made to each individual case or at least when you have a range of sizes and shapes at your disposal. The ideal situation is when, as occurs at Rizzoli, you can order prostheses from the workshop and study them on radiographs and in the skeleton" (Minerva Chirurgica, anno IX, 1954).

Concerning traumatology, Delitala already knew about the metabolism of periarticular ossification, and in the elbow, he recommended their removal not before 6 months after trauma. He also describes a case series with intra-articular fractures which he thought required a good reduction with surgical technique (Figs. 1.13 and 1.14). It should be underlined that at that time traumatology was treated eminently with techniques involving plaster casts. This method was greatly enhanced by the Delitala pressure apparatus, which was used for generations of Italian orthopedic surgeons to correct alignment defects in plaster casts (Figs. 1.15 and 1.16).

A pupil of Delitala, Augusto Bonola, was appointed to the chair of Clinical Orthopedics of Modena in 1945 and backed by his experience at Rizzoli focused mainly on hand and upper limb surgery. His pupil Luigi Celli explored elbow diseases, who in Modena became the point of reference for Italy.

When Delitala retired from the institute in 1953, Rizzoli appointed Raffaele Zanoli to his place. Zanoli completed the book of surgical technique *Atlas of the Main Surgical Operations on the Joints* which was started by Delitala. Zanoli's publications include sports lesions (1960) and treatment of poliomyelitis. Prof. O. Scaglietti took over the chair in 1968, and 1 year later Mario Paltrinieri, who was a professor at Pisa University and had been Putti's pupil, was appointed and remained until 1975. He mainly focused on surgical treatment of joint tuberculosis and parfocal osteotomy for the treatment of nonunion.

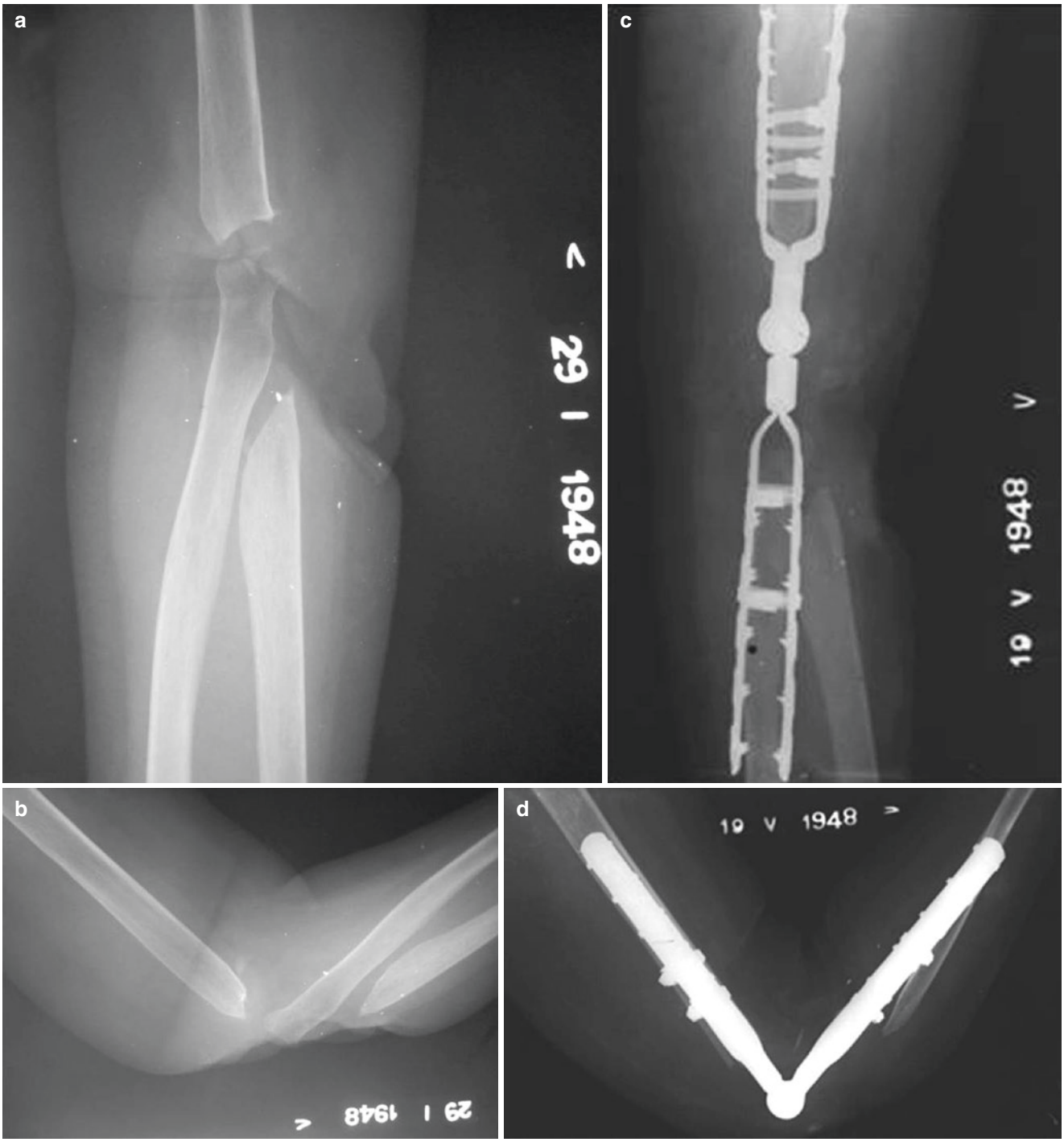
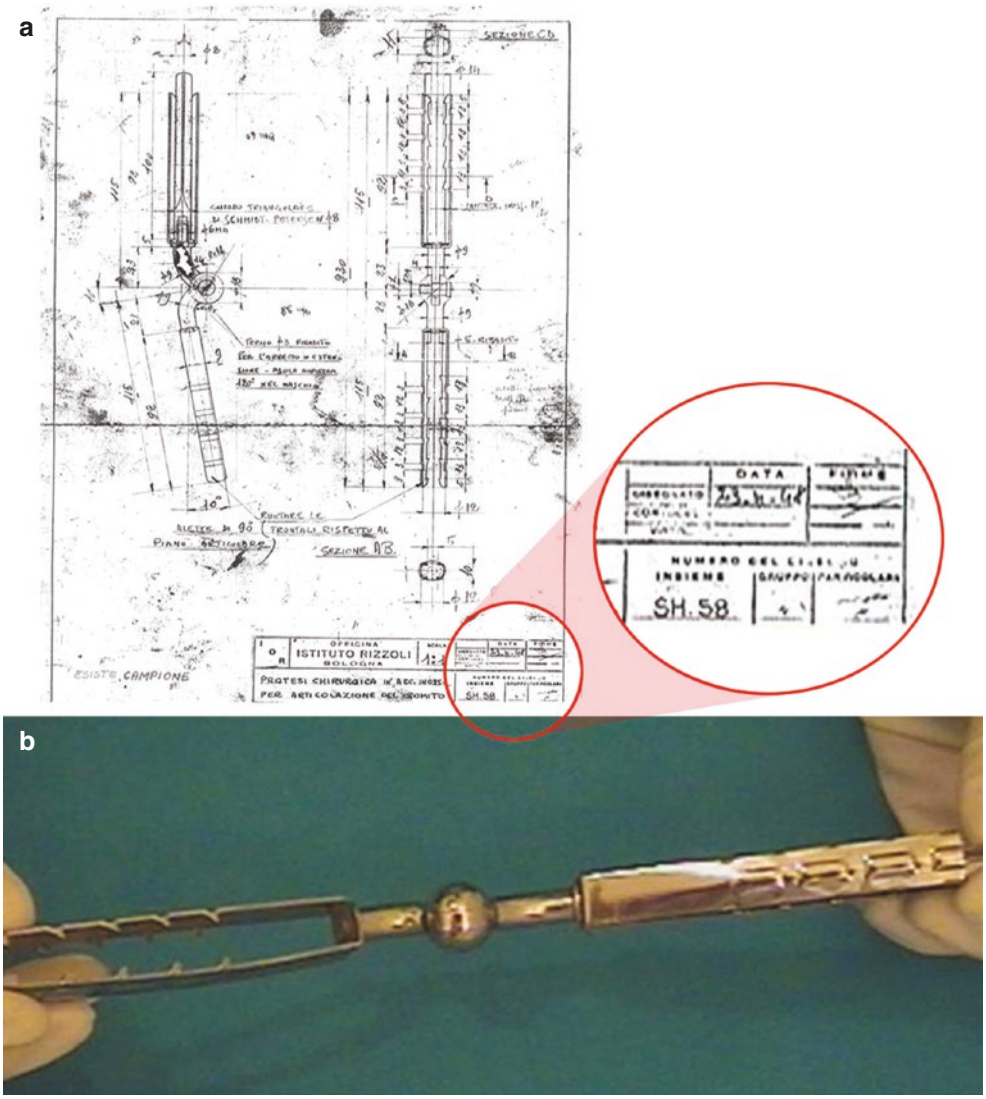


Fig. 1.8 (**a**, **b**) X-ray showing a total bone loss at the elbow as the result of an exploded grenade. (**c**, **d**) Post-op X-ray of the same elbow after a dedicated prosthetic implant, 1948. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

Later the institute was split up into several wards, hospital, and university, which were specialized in different orthopedic diseases (orthopedic oncology, pediatrics, spine, and traumatology). Elbow diseases were thus treated in each ward accordingly: Mario Campanacci treated oncological diseases of the elbow and developed composite prosthesis surgery together with the Rizzoli Workshop (Fig. 1.17), Alessandro Dal Monte treated congenital pediatric diseases (biological arthroplasty), Francesco Ruggieri and Gianfranco Zinghi described the first concepts of AO philosophy in adult



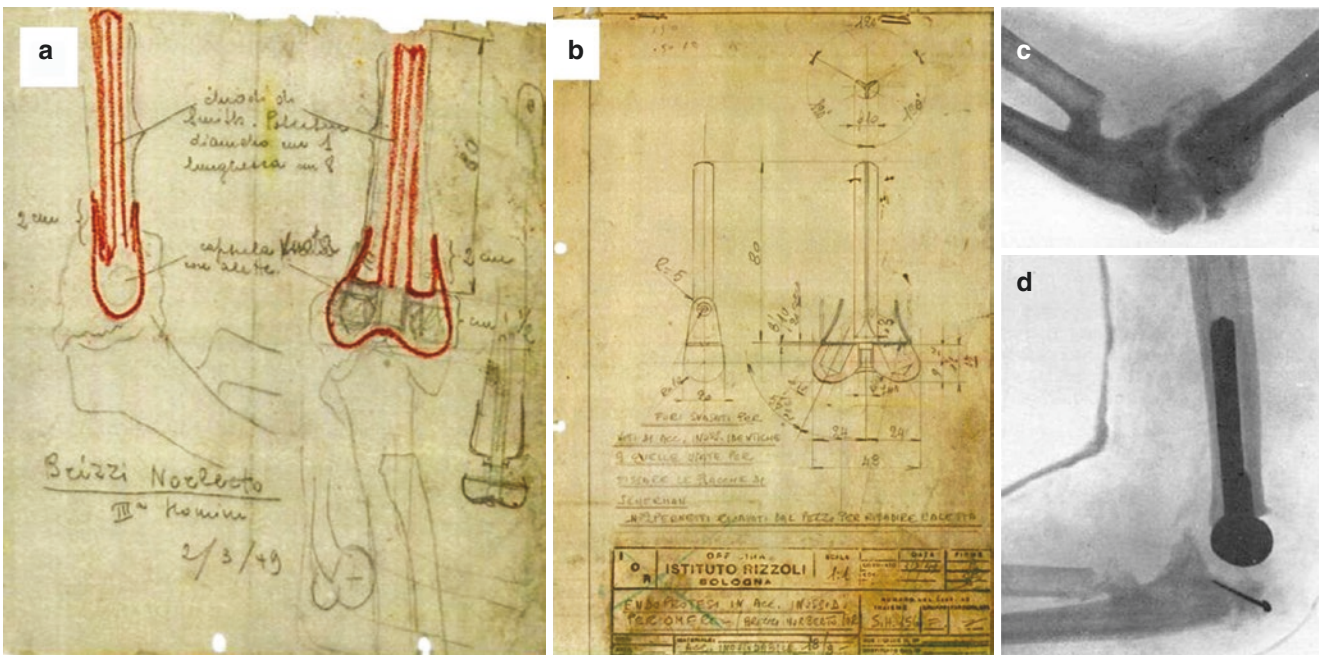


Fig. 1.9 (**a**) Technical project of the custom-made implant shown in Fig. 1.8. (**b**) The original prosthesis after the explant, preserved at the Rizzoli manufacturing. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

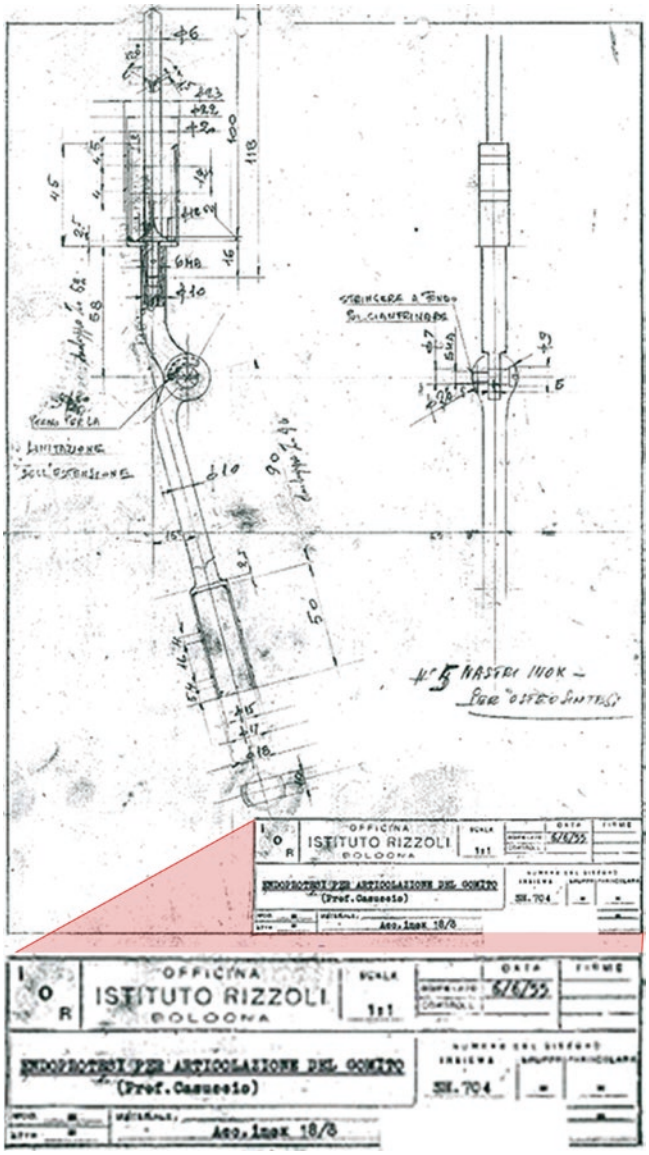


Fig. 1.11 Technical project of the elbow prosthesis implanted by Professor Casuccio for fibrous dysplasia, 1955. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

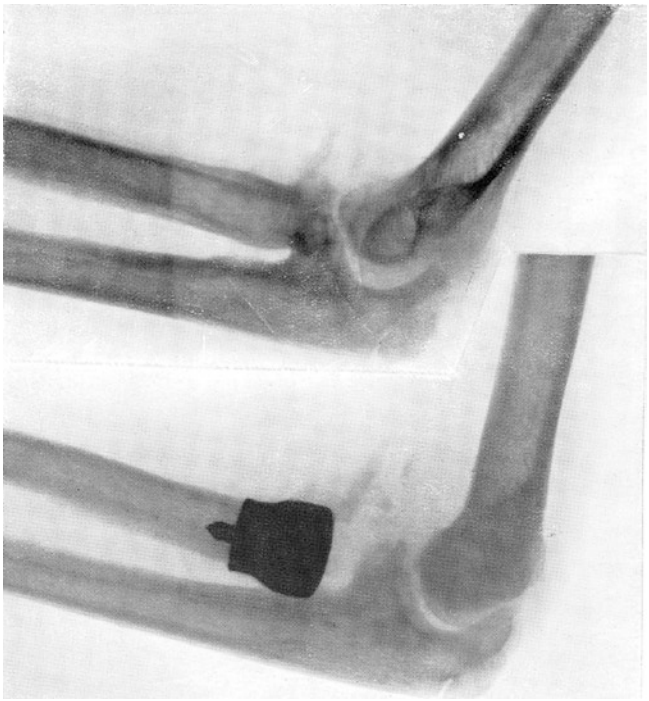


Fig. 1.12 X-ray of an elbow stiff in pronation-supination treated with arthrolysis and radial head prosthesis, 1952. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

Fig. 1.10 Projects for the realization of a distal humerus endoprosthesis for elbow stiffness. (**a**) Drawings from Professor Delitala, 1949. (**b**) Technical project of the same endoprosthesis based on Delitala's handmade project. (**c**) Preop X-rays of the patient's elbow. (**d**) Post-op X-ray showing the prosthetic component in situ. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

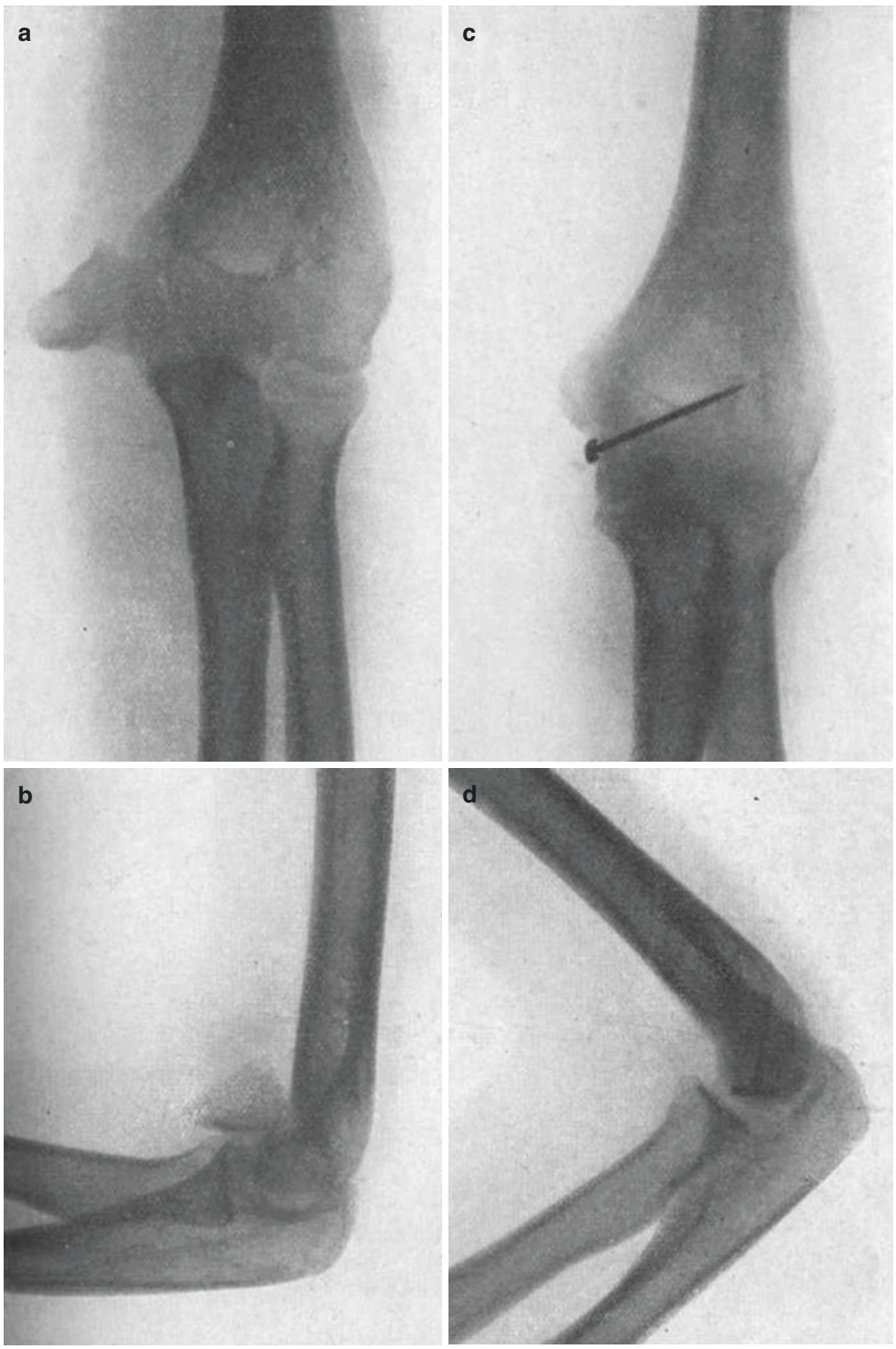


Fig. 1.13 X-ray showing a fracture of the epitrochlea (**a**, **b**), treated with Delitala's pin. (**c**, **d**) Postoperative X-rays showing a good reduction of the fracture. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

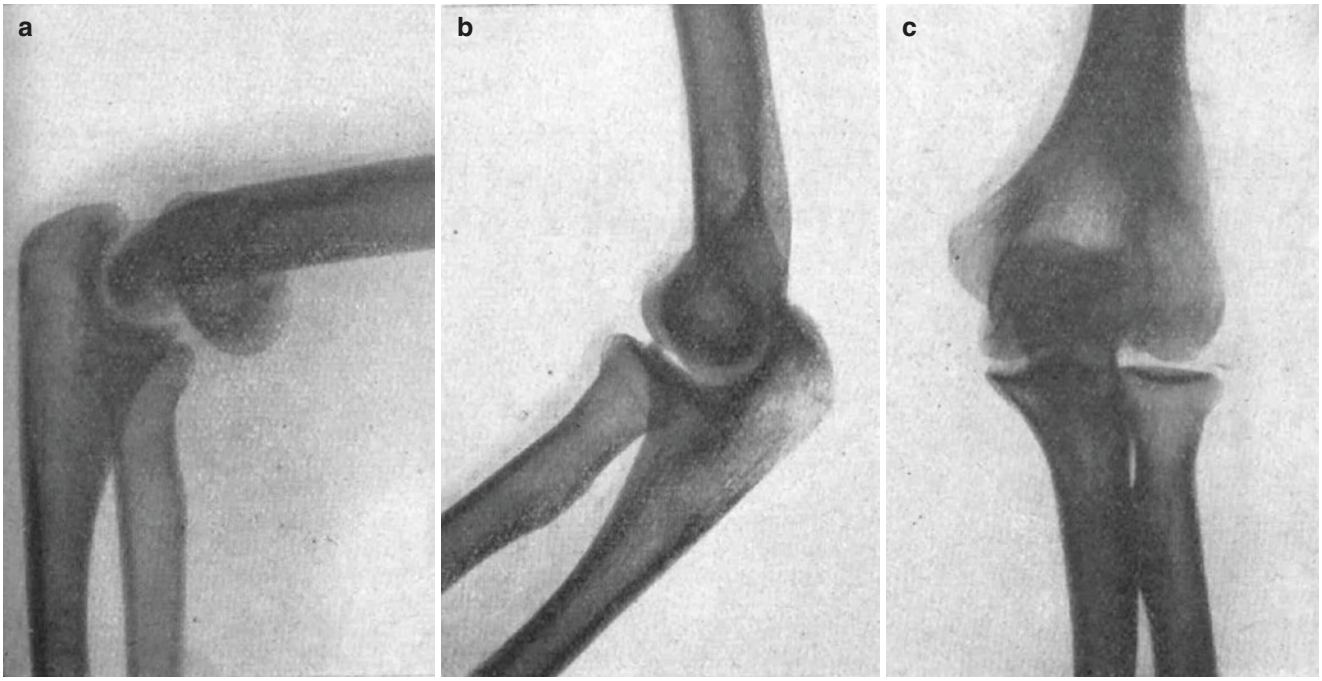


Fig. 1.14 X-ray showing a shear fracture of the capitellum (**a**), treated by Delitala with osteosutures. (**b**, **c**) Postoperative X-rays showing a good reduction of the fracture. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

traumatology, and Leonardo Gui and Giorgio Fontanesi treated degenerative elbow disease and performed a series of total joint replacements (Figs. 1.18 and 1.19).

Gui (and co-workers) was the author of the paper "Fractures and Dislocations" (1959), which was known for its systematic completeness in tackling orthopedic traumas of all kinds; this paper also shows the historical evolution of orthopedics through the ever-increasing use of anatomical Tables (R. Scoto is accompanied by M. Bacialli and L. Negri), photos of the operative field, and radiographic and clinical follow-ups also for traumatic diseases of the elbow.

At that time friendly ties were being made with the Mayo Clinic in Rochester (MN) and overseas specialists in elbow surgery: B. Morrey, SW O'Driscoll, and GJ King.

In 2000 a special shoulder disease unit was set up at the Rizzoli Orthopaedic Institute which continues today, and its biannual course (Rizzoli Elbow Course), linked to the Mayo Clinic, attracts and teaches a network of specialists in elbow surgery from home and abroad.

This brief overview of orthopedics and elbow diseases at the Rizzoli Orthopaedic Institute describes how at the beginning of the twentieth century, the elbow was not the main area of focus for the orthopedic surgeon. The reason for that was the need to address diseases of the lower limbs in order to give the patient more social autonomy. Good alignment and balance were the aims to achieve. Rickets, tuberculosis, and poliomyelitis were the three scourges of the day, and the main objective for the upper limb was to improve movement to be able to carry out personal hygiene, which often came at the expense of stability. Putti was a pioneer of arthroplasty for the treatment of stiffness in flexion-extension and pronation-supination. The comprehensive structure of the Rizzoli Orthopaedic Institute helped to encourage doctors to develop their ideas and accelerate the realization of techniques, devices, and prosthetic implants which have formed the basis for modern orthopedic surgery, often in cooperation with overseas colleagues. Delitala is a forefather of elbow prosthetics, and thanks to him the first implants for total elbow replacement were made at the Rizzoli Orthopaedic Institute. Putti's meticulous archiving system has enabled us to acknowledge those discoveries that the Italian literature had left to fade from memory.

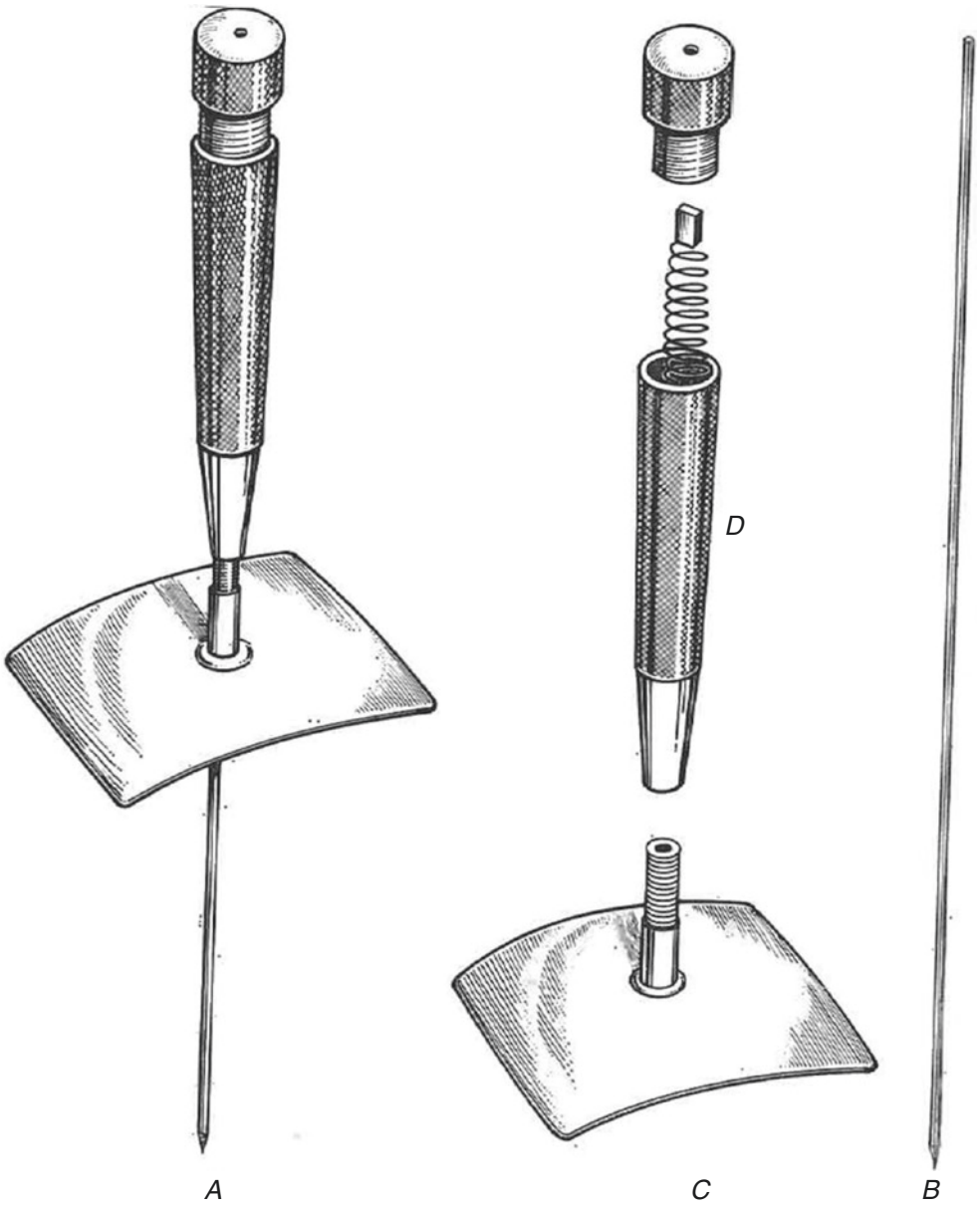


Fig. 1.15 Delitala pressure apparatus, designed to actively improve the reduction of fractures treated conservatively. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

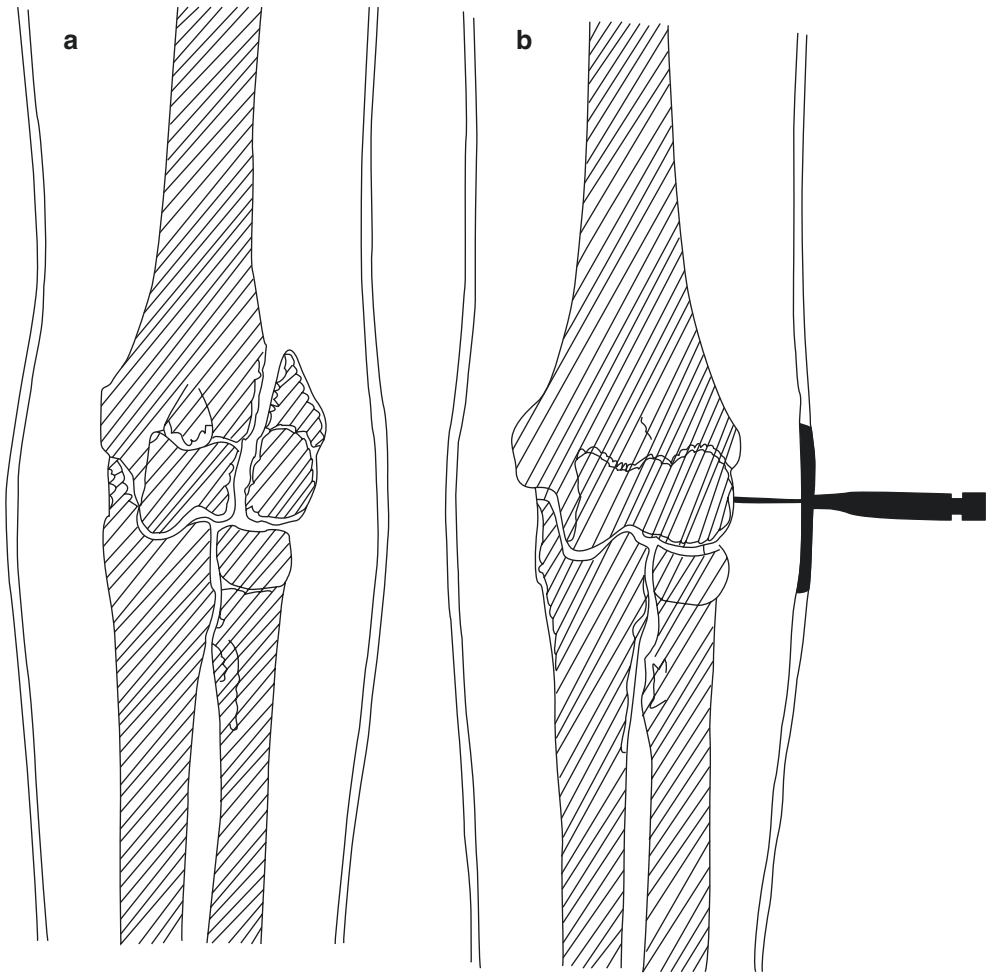


Fig. 1.16 Scheme of Delitala pressure apparatus' technique applied to an elbow fracture. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

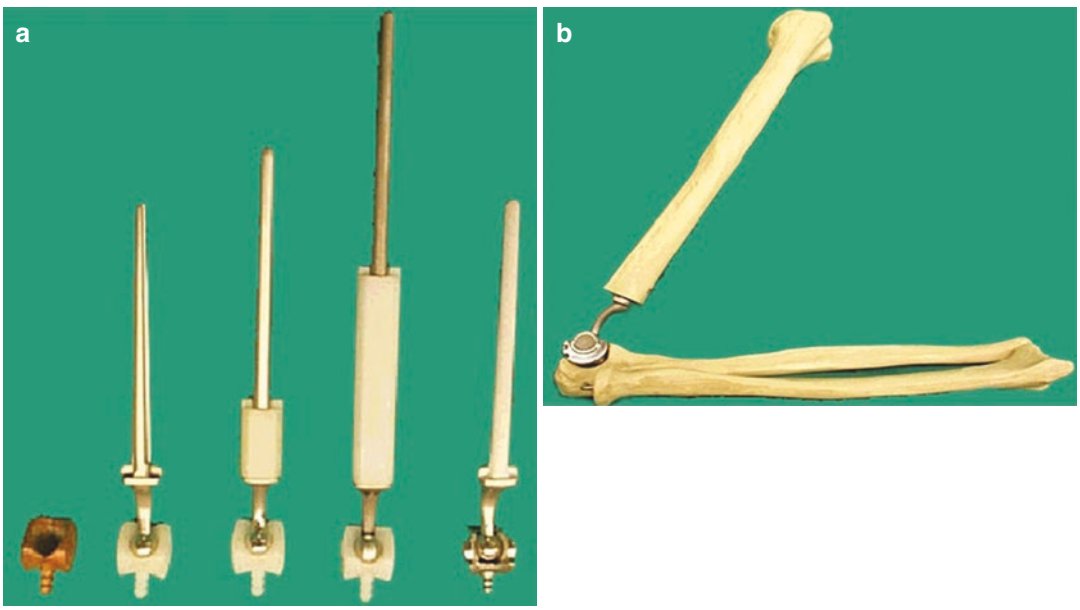


Fig. 1.17 Non-linked composite prosthesis developed for tumor resections. (**a**) Years 1970–1980, from left to right, a wood model for the production of polyethylene component, different metal-on-poly designs, and at last a more recent ulnar component with poly on metal back. The humeral component presents a "snap" locking mechanism. (**b**) Scheme of the implanted prosthesis. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

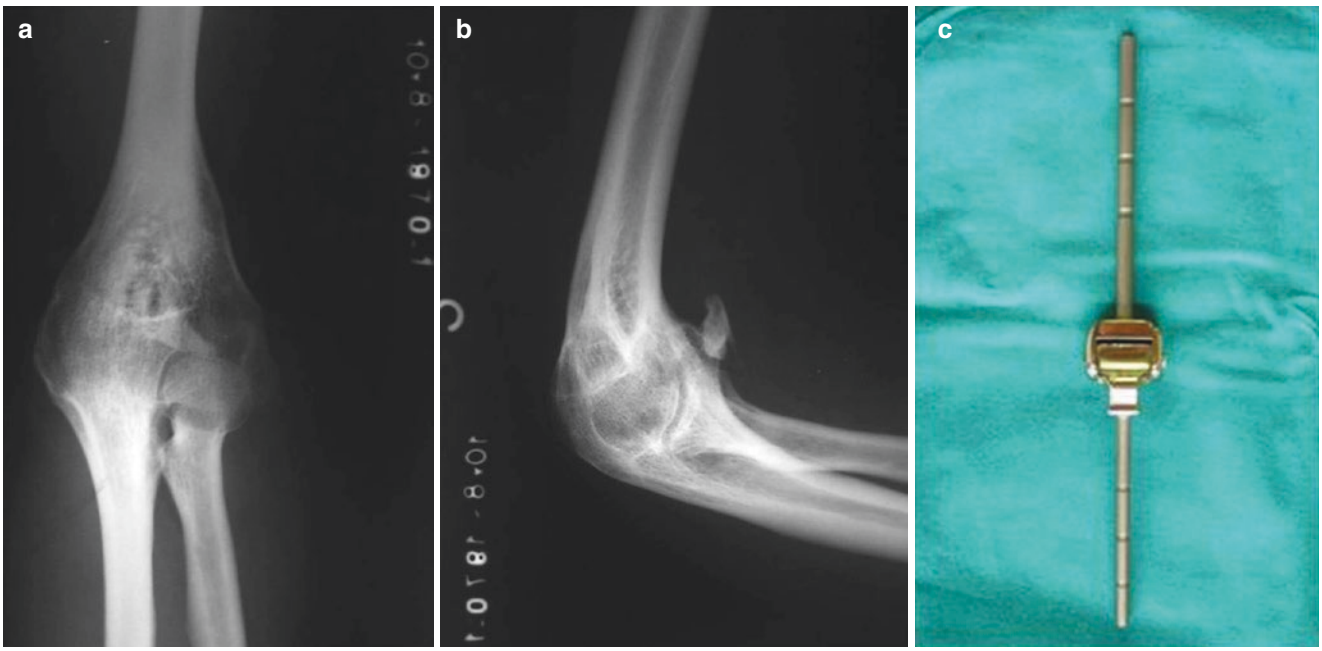
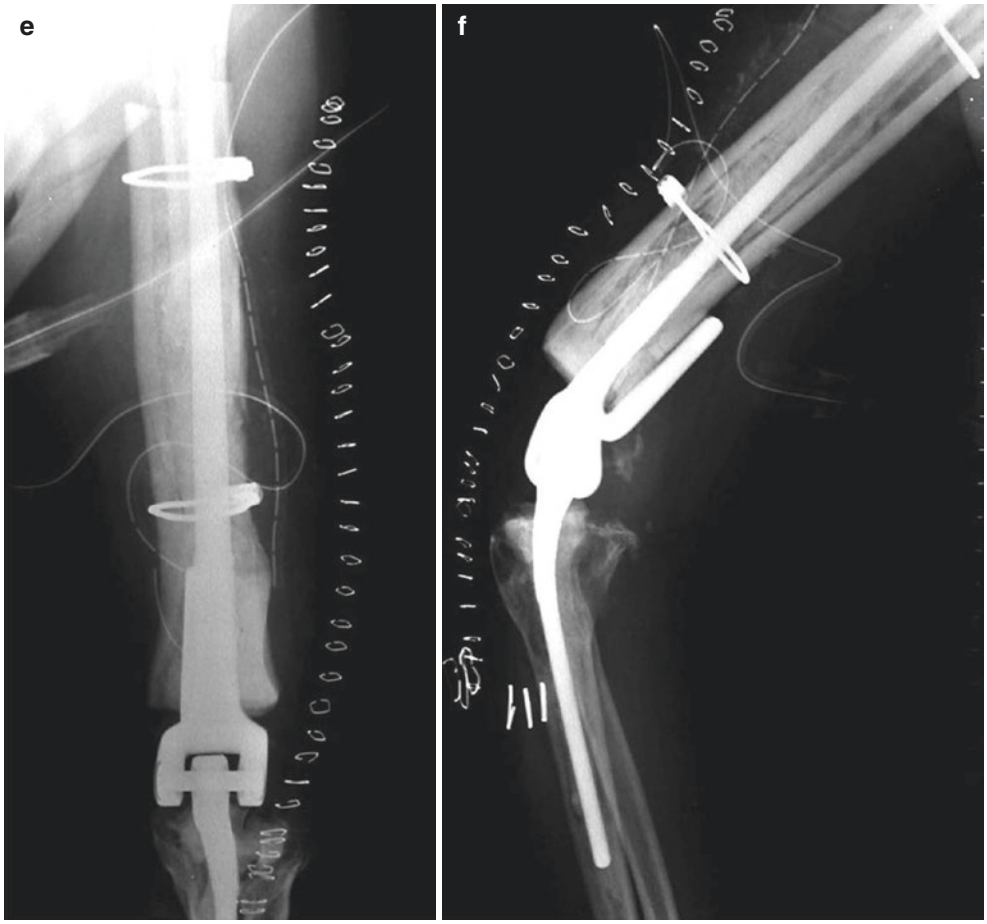


Fig. 1.18 IOR total elbow prosthesis, developed and routinely used by Professor Gui: (**a**, **b**) preop X-ray showing arthritis involvement of the elbow. (**c**) The prosthesis device. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission



Fig. 1.19 (**a**, **b**) Postoperative X-rays of the same patient reported in Fig. 1.18. (**c**, **d**) Follow-up after 24 years showing an aseptic loosening of the implant. (**e**, **f**) Postoperative X-rays of the revised implant. Reproduced from ©Rizzoli Orthopaedic Institute archive with permission

Fig. 1.19 (continued)



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Anatomy and Specimens

2

Alessandro Crosio, Lorenzo Mattei, Davide Blonna, and Filippo Castoldi

2.1 Introduction

A good and safe surgery starts always with perfect anatomy knowledge.

Many consider the elbow's anatomy as one of the most complex for several reasons. Especially because of lack of knowledge of the surgical anatomy of the elbow. The key points to bear in mind are the neurovascular structures that pass both anteriorly and posteriorly at the articular surface.

The cadaver dissection is fundamental, according to us, to learn and explore the neurovascular structures in order to know exactly where they are located. In this way, the surgeon in clinical environment can be confident with the anatomy and can avoid neurovascular injuries.

We are going to describe firstly the anatomy of noble elbow's structures helped by cadaver specimens, and then we described the most frequent surgical approaches to the elbow.

2.2 Nerves

The prevalence of nerve palsy after surgery of the elbow is high. About 40% of patients that underwent surgical exposure of distal humerus develop ulnar nerve neuropathy (Worden and Ilyas 2012). The radial nerve also is frequently injured, fracture's injuries are frequent, but also postsurgical neuropathy is important: after open reduction and fixation, about 12% of patients are affected by radial neuropathy (Ouyang et al. 2013).

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That's why the awareness of the relationship of the ulnar and radial nerves to the humerus in this area is crucial. The median nerve is less frequently affected because it is deeper and protected by the brachialis muscle and only few surgical approach requires to extend nearby the nerve.

2.2.1 Ulnar Nerve

An understanding of the anatomic path of the ulnar nerve is critical to understand how to avoid ulnar nerve problems during fixation or replacement of distal humeral fractures. The first important concept regarding the anatomy of the ulnar nerve is the extreme variability of its course in the distal part of the humerus.

The ulnar nerve is derived from the C8 and T1 nerve roots and is a terminal branch of the medial cord. In the upper part of the arm, the ulnar nerve is posteromedial to the brachial artery, posterior to the intermuscular septum, and anterior to the medial head of the triceps muscle.

The ulnar nerve runs initially in the anterior compartment of the arm and goes posteriorly through the medial intermuscular septum at an average distance of about 6–8 cm proximal to the medial epicondyle with a range between 5 and 11 cm. In approximately 40% of cases, however, the ulnar nerve passes posteriorly without crossing the medial intermuscular septum and then transitions from anterior to posterior at a more distal point.

Approaching the medial compartment of the elbow is essential to identify, isolate, and protect the ulnar nerve to avoid injuries.

The point of passage is figured by a simple hole in the membrane or by a fibrous channel formed by a splitting of the medial intermuscular septum.

Classically, a fibrous tissue in the vicinity of the medial intermuscular septum, particularly evident at the level of the passage of the nerve, is described, and it is called arcade of Struthers. Many authors tried to describe on cadaver specimen's structure, but with unshared results (Tubbs et al. 2011).

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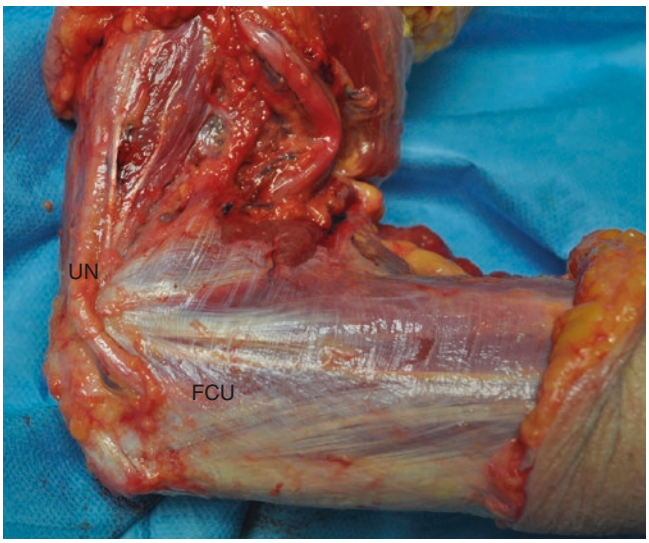


Fig. 2.1 UN ulnar nerve, FCU flexor carpi ulnaris, the continued line indicates the Osborne ligament. Distal to the FCU, the arcuate ligament is marked

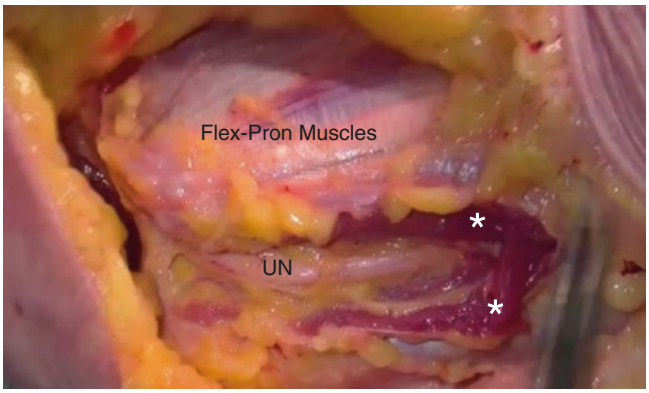


Fig. 2.2 Dissection of the FCU heads, taken care to the first motor branch of the ulnar nerve, * FCU's heads

According to our clinical experience, the presence of a clear structure of a dense, fibrous, tendon-like membrane, stretched between the medial intermuscular septum and medial head of the triceps, is extremely rare. It is however important to explore the proximal ulnar nerve until the intermuscular septum to release every dense structure that could lead to postoperative neuropathy.

At the level of the elbow, the ulnar nerve engages in the cubital tunnel, an elliptical fibro-osseous tunnel, which is comprised proximally by the Osborne ligament (a fibrous structure stretched between the two heads of the FCU) and is formed distally by the deep flexor/pronator aponeurosis (approximately 5 cm distal to the medial epicondyle) as presented in Fig. 2.1.

This arcuate ligament of Osborne is about 4 mm wide and serves to prevent subluxation of the ulnar nerve with forearm motion. The joint capsule and the posterior and transverse parts of the medial collateral ligament form the floor of the cubital tunnel (Pecina et al. 2001). This is an aspect to take care during surgical approaches to repair medial collateral ligament.

Distal to Osborne ligament, an arcuate fibrous structure is present between the two heads of the FCU. This is the arcuate ligament that could be a potential cause of ulnar nerve compression (De Maeseneera et al. 2015).

Distal to the epicondyle, in subcutaneous tissue, medial antebrachial cutaneous nerve branches are present. They originate from median nerve and, in 90% of cases, pass distal to the epicondyle and anterior to the ulnar nerve (Masear et al. 1989). During dissection, surgeons have to take care of it (Xing and Tang 2014).

The dissection has to start proximal to epicondyle to identify the ulnar nerve. After the entrance in between humeral and ulnar heads of FCU, the first motor branch to flexor muscles starts; the surgeon must be careful to preserve it during dissection as showed in Fig. 2.2.

2.2.2 Radial Nerve

The radial nerve could be damaged by direct injury, by the sharp bony fragments of the fracture, or during the surgical approach (Chaundry et al. 2010).

The radial nerve arises, along with the axillary nerve, from the posterior cord of the brachial plexus. It runs posteromedially in the arm and descends into the arm moving laterally between the medial and lateral heads of the triceps closely to the radial nerve groove of the humerus. Moving laterally, the radial nerve pierces the intermuscular septum, and it runs in the anterior compartment of the arm between the biceps brachii muscle and the brachialis muscle. In the cubital fossa, approximately at the level of the radiohumeral joint, it splits into its two terminal branches: the superficial radial nerve and posterior interosseous nerve (Fig. 2.3). The posterior interosseous nerve (PIN) passes adjacent to the joint capsule at the level of the radial head and through the supinator muscle, while the superficial anterior nerve runs distally in the forearm underneath the brachioradialis, lateral to the radial artery.

Kamineni et al. (2009) demonstrate the importance of the interepicondylar distance as a reliable measurement to predict the position of the radial nerve. They identified the distance between the lateral epicondyle and the point where the radial nerve crosses the humerus in the mid-lateral plane to be 1.4–1.7 times the interepicondylar distance for a given patient. In Fig. 2.4, the anatomical landmarks are presented.

During the preoperative planning, we usually identified "absolute secure area" corresponding at the interepicondylar

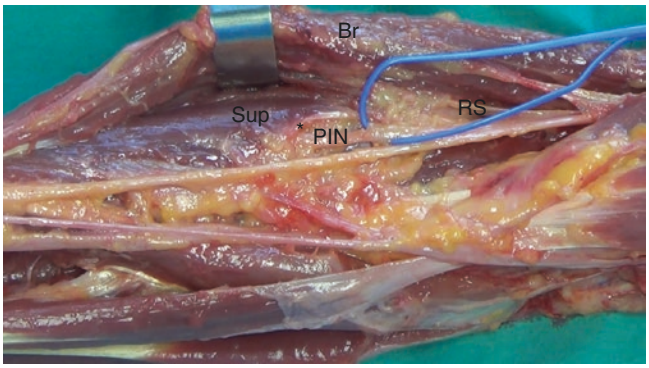


Fig. 2.3 Terminal branches of the radial nerve, *PIN* posterior interosseous nerve, *RS* radialis superficialis, *Br* brachioradialis, *Sup* supinator, * Frohse arcade

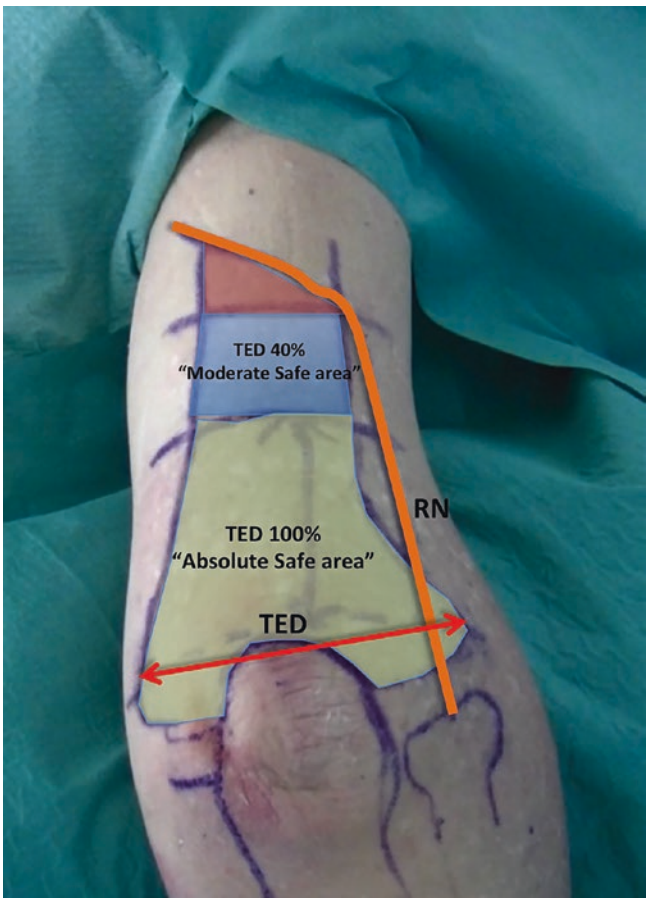


Fig. 2.4 Anatomical landmarks as described by Kaminemi. *TED* transepicondylar distance, *RN* radial nerve

distance, where we can work safely, and another "moderate safe area" corresponding at the measure increased by 40%. This is the point where the radial nerve passes from the anterior to the posterior compartment of the arm.

Another reliable landmark of the course of radial nerve is suggested by the triceps aponeurosis. Chaundry et al. (2010) demonstrate that the mean distance of the radial nerve from the triceps aponeurosis was over 20 mm; at its distal end, the radial nerve ran a course with a mean distance of 12 mm to the lateral border of the aponeurosis.

This information is very important during the preoperative planning, in order to decide if an accurate dissection of the radial nerve is necessary or not, and during surgery when an anatomical precontoured lateral plate is used for the fixation or when you plan where to place humeral half pins for external fixators. The knowledge, in advance, of the need to isolate the radial nerve has some advantages including mental preparation of the surgeon, a more accurate prediction of the length of the intervention, and the ability to foresee the use of sterile tourniquet in cases of fractures with a more proximal extension.

The PIN is at risk when it winds around the radial neck in the belly of the supinator muscle. This nerve is embedded in the radial tunnel, a 5 cm-potential long space. The boundaries of the radial tunnel are the humeroulnar joint and the deep layer of the supinator muscle posteriorly, the fibrous attachments between the brachioradialis muscle, the brachialis, and the extensor carpi radialis brevis muscle laterally, the superficial layer of the supinator muscle anteriorly, and the biceps brachii muscle medially. A bottleneck along this tunnel is the proximal border of the supinator muscle: the arcade of Frohse (Fig. 2.3). In most cases, entrapment of the PIN occurs at this narrow passage.

Different surgical procedures such as radial head replacement or osteosynthesis, reinsertion of the distal head of the biceps, or lateral collateral ligament reconstruction put the PIN at high risk of injury. The nerve in fact could be damaged by direct injury and by the retractor's compression. Two tricks have been described in literature to reduce the risk of injury of the nerve: identification and protection of the PIN by dissection of the supinator and placement of the arm in full pronation in order to move the PIN out of the surgical field.

Lawton et al. (2007) describe an anatomic safe area of 4.0 cm from the radiocapitellar joint in supination that increases to a 4.3 cm in pronation. They conclude, contrasting previous assertion, that pronation did not provide a clinically significant increase in safe zone. Hackl et al. (2015) in a recent study have suggested to use the radial tuberosity as bony landmark to predict the location of the PIN. The nerve can be located approximately 5 mm distal to the most prominent point of the radial tuberosity in pronation and 1 cm proximal to it in supination. That can be useful during a ventral surgical approach.

From our experience, we suggest to approach very carefully to this area, without blindly trusting the increase of the safe area by the pronation of the forearm. Moreover, great caution is needed in positioning the retractors very tight to the bone (Fig. 2.5).

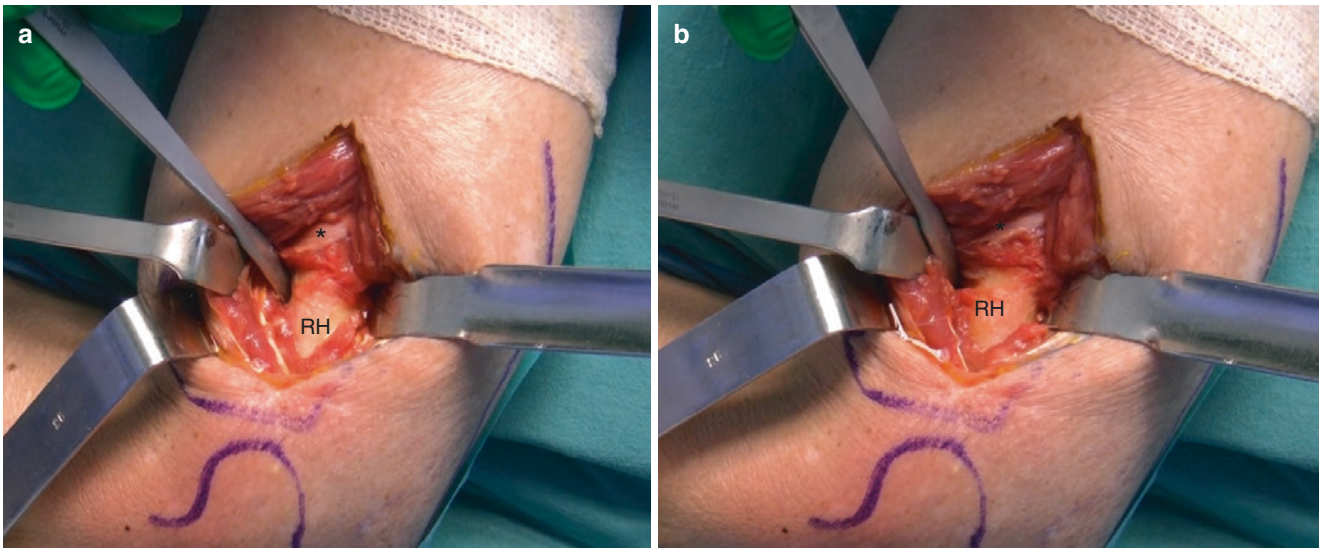


Fig. 2.5 Exposure of the radial head (RH) and posterior interosseous nerve (PIN) in fully supination (**a**) and pronation (**b**). In a, the PIN is superficial and is stretched by the retractor. In b, the nerve goes deeply and is quite distant to the retractor

The superficial radial nerve arises at the level of radiohumeral joint. It passes under the brachioradialis and reaches the subcutaneous tissue between brachioradialis tendon and the extensor carpi radialis longus in the midforearm. This nerve gives the sensory innervation of the lateral forearm. In some cases, the passaging between brachioradialis and ECRL could be the site of compression (Knutsen and Calfee 2013).

2.2.3 Median Nerve

The median nerve is formed from branches of the medial and lateral cords of the brachial plexus. It receives its sensory contribution predominantly from the lateral cord and its motor fibers predominantly from the medial cord.

It runs on the median side of the arm, near the brachial artery between brachialis and biceps brachii. In the proximal third of the humerus, it passes lateral to the artery, and then it crosses the artery and runs on the medial side in the distal arm and into the cubital fossa. In this part, the nerve does not give any branches.

Before the antecubital fossa, it passes under the ligament of Struthers. The supracondylar spurs and the Struthers ligament were described by Struthers in 1848 (Jesus and Dellon 2003). The ligament is an anatomic variant that extends from a small, vestigial supracondylar process on the anteromedial diaphysis of the humerus to the medial epicondyle, about 5 cm above the medial epicondyle. It's described in about 1% of population.

This ligament connects the bony spur with the medial epicondyle. This structure forms a fibro-osseous roof of a tunnel in which it passes the median nerve and brachial vessels. Sometimes in this tunnel, median nerve and brachial artery could be compressed. The surgeons have to bear in mind this structure especially in patients with persistent median nerve compression symptoms and a previous carpal tunnel release (Jesus and Dellon 2003).

Distally, it lies between the brachialis muscle and the medial intermuscular septum and then passes through the antecubital fossa and under the lacertus fibrosus (bicipital aponeurosis). The nerve next travels between the deep and superficial heads of the pronator teres and in some cases posterior to the pronator teres. Close to the deep head of pronator teres and the arch of flexor digitorum superficialis originates the anterior interosseous nerve.

Related to elbow surgical exposure, the median nerve can be damaged especially during anterior access to cubital fossa. It is important to retract soft tissues gently during reinsertion of distal biceps in order to avoid injuries to either median or posterior interosseous nerve. The placement of the retractors laterally to the radius could injure the PIN. In Fig. 2.5, the PIN is showed and lies just underneath the distal tendon of the biceps brachii (Fig. 2.5).

2.3 Ligaments

In literature the anatomy and biomechanic that allow the elbow to work properly is well and extensively described. In this chapter, we are going to describe the anatomical remarks about the ligaments and stabilizing structures of the elbow that correlate with surgical approaches.

The C-shaped proximal ulna and the anteversion of the distal humerus give the elbow an intrinsic stability primarily in anteroposterior movement. The coronoid process, which limits the anteposition of the humeral articular surface, acts this role, and this work is helped by the soft tissue structures. The primary and secondary stabilizers are described by O'Driscoll et al. (2000). The primary stabilizers are the medial (MCL) and lateral collateral ligament (LCL) complexes. The radial head, the anterior and posterior capsule, and the flexor/extensor act as secondary stabilizers. O'Driscoll also described dynamic stabilizers that are the biceps, brachialis, anconeus, and triceps.

2.3.1 Primary Stabilizers

2.3.1.1 Lateral Collateral Ligament Complex

The LCL complex originates from the lateral epicondyle at the isometric point of the elbow and consists of four components: the lateral ulnar collateral ligament (LUCL), the lateral radial collateral ligament, the accessory lateral collateral ligament, and the annular ligament (Mehta and Bain 2004). The LUCL is a thickening of the capsule and is the primary lateral stabilizer. It inserts on the tubercle of the supinator crest of the ulna. The lateral radial collateral ligament blends with the annular ligament, which encircles the neck of the radius. It functions as a varus restraint and stabilizes the annular ligament. In Fig. 2.6, the lateral ligament complex is presented (Mehta and Bain 2004). During the lateral exposure of the elbow, care should be taken to preserve the lateral complex. Using the Kocher's interval, the LUCL lies just underneath the extensor muscles and could be injured during excessive dissection. During Kaplan approach, the radial collateral ligament is in front of the surgeon that could split this structure to reach the radial head (Fig. 2.6).

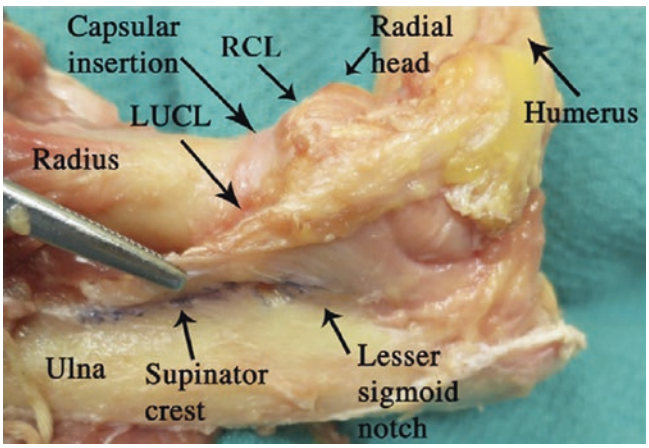


Fig. 2.6 Lateral compartment without muscular structure. The LUCL lies underneath the radial head and inserts on the supinator crest. The radial collateral ligament (RCL) is a shorter branch that is fused to the annular ligament

2.3.1.2 Medial Collateral Ligament Complex

The MCL complex consists of three bands: the anterior band, the posterior band, and the transverse band. The anterior and posterior bands originate from the anteroinferior aspect of the medial epicondyle. The anterior band is tensed between the medial epicondyle and the medial aspect of the sublime tubercle and acts as the most important valgus restraint. The posterior band of the MCL is the primary restraint against pronation of the ulna on the humerus (Bain 1999), and it is tensed to the medial margin of the ulna. The so-called transverse band is just the distal expansion anterior and posterior band and has no role in elbow instability (Bell 1998). There are different surgical approaches to the medial elbow; as described below, the best way to view and visualize the MCL complex is the flexor split approach Tubiana et al. (2000) in which the medial complex is just in front of the surgeon. This way allows visualizing completely the sublime tubercle and performing the reduction and fixation easily. In Fig. 2.7, the MCL complex is presented after accurate soft tissues dissection.

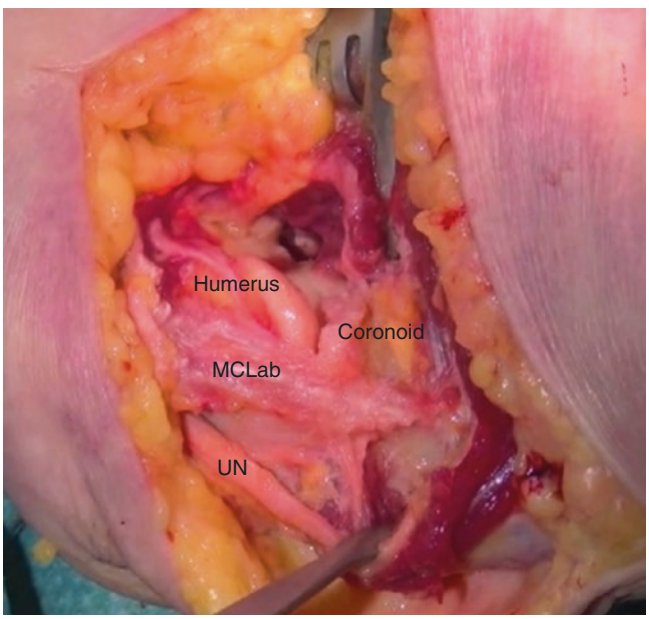


Fig. 2.7 The anterior bundle is evident (MCLab); it extends between the epicondyle and the sublime tubercle. The ulnar nerve (UN) is just underneath the ligament

2.3.2 Secondary Stabilizer

The proximal end of the radius is an important stabilizer in valgus of the elbow, but its activity is evident when an injury to the MCL complex is present. The anterior capsule is inserted just ahead the coronoid process and correlates on the MCL and brachialis muscle to give stability to the elbow.

The lateral and medial muscle structures are other secondary stabilizers of the elbow.

Laterally, the anconeus is a short muscle innervated by the radial nerve. It originates from the medial epicondyle and takes place distally to the lateral olecranon; it is a secondary stabilizer and a week extensor of the elbow. This muscle works in cooperation with the brachialis. It is inserted on the coronoid process. Leonello et al. (2007) described two heads of the brachialis. The deeper one is radially oriented and runs anteriorly and parallel to the ULCL. The anconeus is posterior and parallel to the ULCL, so these two muscles together form a dynamic muscular sling, which protects the ULCL when it is threatened with forced supination of the ulna on the humerus (Leonello et al. 2007).

The lateral muscle belly is represented by the extensor muscles. Just above the anconeus on the lateral epicondyle, a common insertion is identified. From the conjoint tendon depart the extensor carpi ulnaris, the extensor digiti communis, and the extensor carpi radialis brevis and longus. The Kocher's approach is between the anconeus and extensor carpi ulnaris. The Kaplan approach is in the middle of the conjoint tendon of the extensor muscles.

Deeply to the extensor muscles runs the supinator in which lies the posterior interosseus nerve.

The flexor pronator mass originates from the medial epicondyle. During the medial access, the surgeon can decide to split the humeral and the head of the flexor carpi ulnaris to reach the joint, or it is possible to find, volarly, the supinator and the brachialis muscle fibers to perform the Hotchkiss approach. The interval is identifiable by the different orientations of the muscles: the pronator's one runs distally, and the brachialis' one is vertically oriented. It is important to accurately identify this interval in order to protect the median nerve and brachial artery that lay just behind the brachialis muscle.

2.4 Surgical Approaches

2.4.1 Posterior Approach

O'Driscoll (2000) said "The front door to the elbow is at the back." That's why we start describing the posterior approach that has also been named "universal approach." With this surgical approach, the surgeon can manage the posterior, lateral, medial, and, if is adequately extended, also the anterior part of the joint, with a good exposure of all the anatomical structures.

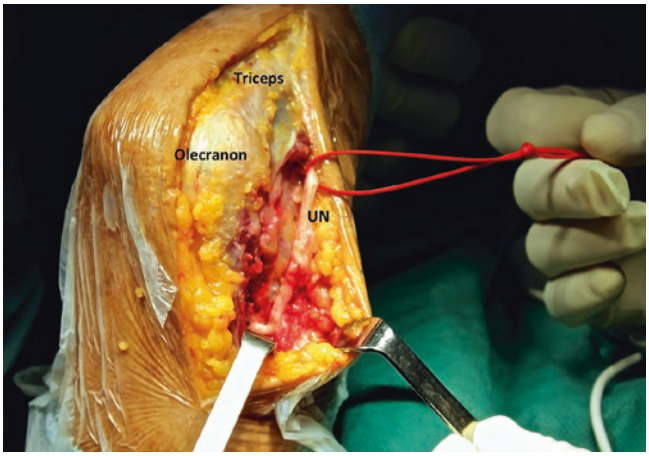


Fig. 2.8 Isolation of the ulnar nerve during posterior approach

Usually, the patient is in lateral decubitus with the arm supported by a bolster. In our clinic, we prefer a supine position, with the affected arm crossing the chest in order to have the humerus in vertical position. A pneumatic tourniquet is used to work safer, especially during the nerve isolation; a sterile tourniquet is preferred when a proximal extension is required.

A posterior longitudinal incision between the lateral and medial brachial cutaneous nerves is performed just medial or lateral to the tip of the olecranon to avoid wound dehiscence and plate exposure. Once the fascia overlying the triceps brachii is identified, a full-thickness incision is carried down. We suggest to carefully isolate and dissect the ulnar nerve and to transpose it anteriorly. During surgery, to prevent excessive traction of the nerve, we prefer to use a simple knot of the vessel loop instead of clamping it with heavy tools as showed in Fig. 2.8.

The management of the triceps is guided by the pathology, the fixation devices or implant type, and by surgeon preference. Based on these, we can classify the posterior approach in olecranon osteotomy, triceps on or triceps sparing, triceps splitting, TRAP, and Bryan-Morrey exposure.

From our experience, the triceps on approach, when is practicable, is the one that gives the best clinical results. Independently on the triceps management, a careful reconstruction of the extensor mechanism is mandatory to avoid complications and to allow a rapid rehabilitation.

As demonstrated by Dachs et al. in the total elbow arthroplasties, the triceps on technique results in good outcomes with less complication as triceps rupture and extensor mechanism insufficiency, when compared with triceps detaching. They have not found any complication in cementing technique or duration of surgery when the

surgery was performed by a skilled surgeon (Dachs et al. 2015). Concerning trauma patients with distal humerus fractures, the triceps on and the triceps detaching approach will result in reliable union and similar functional outcomes. However, faster rehabilitation and better range of movement were achieved with a triceps sparing technique (Illical et al. 2014).

In our clinic, we try to maintain extensor continuity of the elbow and to avoid olecranon osteotomy.

2.4.1.1 Olecranon Osteotomy

With this technique, a "V" osteotomy at the bare spot on the trochlear notch was performed. Usually, the osteotomy can be performed with a sagittal saw, and the articular side should be breached with an osteotome to create an irregular joint surface that helps the later reduction and fixation. Then, the olecranon is reflected proximally, separating the medial triceps from the medial intermuscular septum and the lateral triceps from the anconeus and lateral intermuscular septum. The anconeus is denervated by this approach. After the surgical procedure, the surgeon can repair the osteotomy with different techniques including tension band, plate-and-screw fixation, or intramedullary screw.

2.4.1.2 Triceps Splitting

This technique originally described by Campbell (1932) consists in a longitudinal splitting of triceps muscle and tendon to expose the distal humerus. The triceps muscle and its tendon are splitted, and two full-thickness flaps are created, leaving the extensor mechanism in continuity with the forearm fascia and muscle medially and laterally; the triceps insertion on the ulna is carefully subperiosteally reflected, laterally with the anconeus and medially with the flexor carpi ulnaris, exposing the olecranon. After surgery is performed, the triceps could be addressed with transosseous suture on the olecranon.

2.4.1.3 Bryan-Morrey Approach (or Triceps Reflecting) (Bryan and Morrey 1982)

With this approach, a good exposure of the medial column could be obtained. We recommend not to use this approach to fix lateral column fracture, especially if they have proximal extension. Once isolated, the triceps, the medial aspect of it, is proximally elevated from the humerus and from the ulna, sharply dissecting Sharpey's fibers. To achieve a nice exposure of the medial humerus, reflect it over the lateral epicondyle. If a total elbow arthroplasty is planned, a complete release of the collateral ligaments is necessary to allow elbow dislocation. In the other surgical procedures, pay attention to not detach the medial collateral ligaments from its origins. Nonabsorbable sutures are necessary to reinsert the extensor mechanism at the end of surgery.

2.4.1.4 Triceps-Reflecting Anconeus Flap (TRAP) Approach

TRAP technique has been described by Shawn O'Driscoll (O'Driscoll et al. 2000) and could be used in many cases both in distal humeral fracture and in elbow arthroplasties. The skin incision is on the posterior aspect of the elbow; the interval between the anconeus and the extensor carpi ulnaris is opened, and then the anconeus is elevated from the ulna and from the capsule. Proximally, the triceps is released from the lateral supracondylar ridge of the humerus. As in the Bryan-Morrey approach, the triceps is elevated and reflected. More distally, the medial release of the anconeus from the ulna is connected with the previously performed lateral dissection. Then, the triceps and anconeus are reflected proximally as a unique structure in an apex-distal V-shaped flap to achieve a good exposure of the articular surface. Attention must be paid to preserve the lateral collateral ligaments.

2.4.1.5 Triceps On

Preserving the triceps insertion on the olecranon, this approach allows a good visualization through medial and lateral windows. This is our main choice to manage an articular not fixable fracture with a prosthesis. To prevent malrotation or inadequate preparation of the ulnar canal, a careful release of the medial attachment is needed.

The medial and lateral borders of the triceps muscle are elevated using a finger or a scissor from their respective intermuscular septa.

The lateral dissection is continued distally in the Kocher interval elevating the anconeus muscle along with the triceps and preserving its neurovascular supply. In Fig. 2.9, it clearly showed the interval between anconeus and triceps. Using a scalpel to detach the triceps from the posterior aspect of the humerus, the two windows are connected.

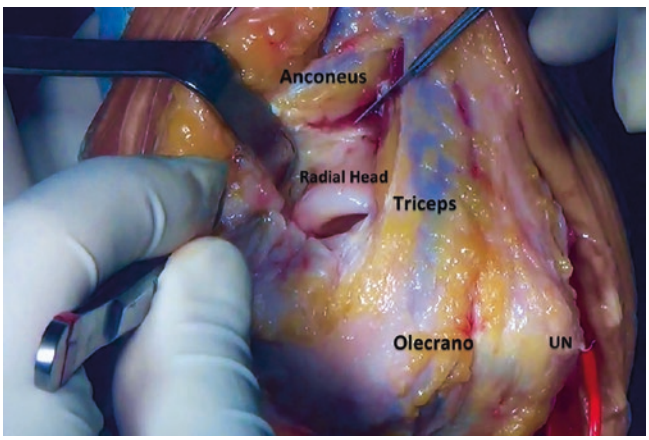


Fig. 2.9 During triceps on approach, it is fundamental to preserve the interval between anconeus and triceps to respect the neurovascular supply of the anconeus

Then, the surgeon can work on both sides, displacing the triceps on the other side.

The main advantage of this approach is that the rehabilitation program can be started immediately.

2.4.2 Lateral Approaches

Surgeons frequently have to approach the elbow laterally. These approaches are indicated to perform surgical procedures on radial head and on ulnar lateral collateral ligament and capitulum humeri. To reach the joint space, it is possible to use the interval between extensor supinator muscle bellies (Axelrod 2014).

One of the most employed ways is the Kocher's approach (Morrey and Bryan 1988).

The skin incision is made for 5 cm centered on epicondyle (Fig. 2.10).

Then the interval between the extensor carpi ulnaris and anconeus is identified and opened by blunt dissection from the tip of the epicondyle. The interval could be identified through divergent muscle fibers and arterial perforator as presented in Fig. 2.11.

The lateral ulnar collateral ligament lies just behind the extensor carpi ulnaris; the surgeon must take care, during dissection, to this primary stabilizer of the elbow. Just above to the lateral ulnar collateral ligament, the radial collateral ligament can be identified just attached to the annular ligament. With this approach, it is possible to extend distally on the shaft of the radius without injuring the PIN because the supinator mass is elevated with the surrounding tissue. The surgeon could reach at maximum 6 cm from the head of the radius with this way. See the previous paragraph to see the anatomical relationship between the NIP and the radial head and shaft.

Another interval could be employed to reach the lateral compartment. The surgeon can split the tendon of extensor digitorum communis as described by Kaplan (1941). This approach is useful in cases in which the lateral collateral ligament is intact. In Fig. 2.12, the LCL is splitted and marked with *; the annular ligament has been cut. The annular ligament has to be splitted in the middle of the radial head.

Further extensions are possible. Proximally, it is possible to split the lateral collateral ligament, but an accurate reconstruction is required. Distally, an extension to the radial tuberosity is possible, but the forearm has to be maintained pronate, and gentle pressure on the retractors has to be applied in order to preserve posterior interosseous nerve; moreover, the surgeon must take care not to go too distally and to split the fibers of the supinator in order to not injure the PIN (Axelrod 2014).



Fig. 2.10 The skin incision for the lateral approach to the elbow is shown; the incision is centered on the epicondyle and goes distally to the radial head

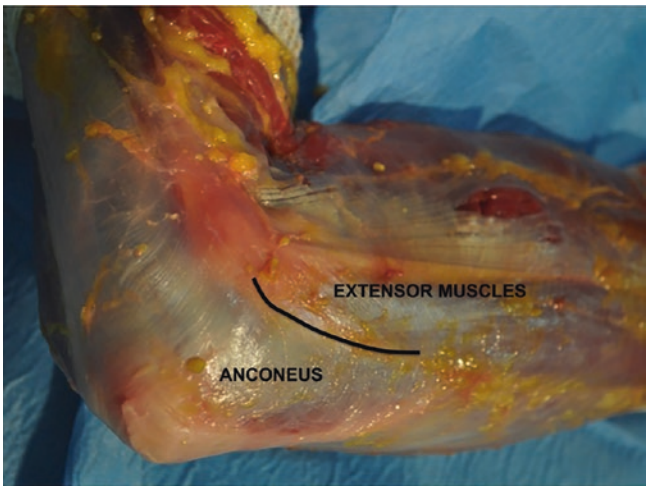


Fig. 2.11 The interval between extensor carpi ulnaris and anconeus is shown

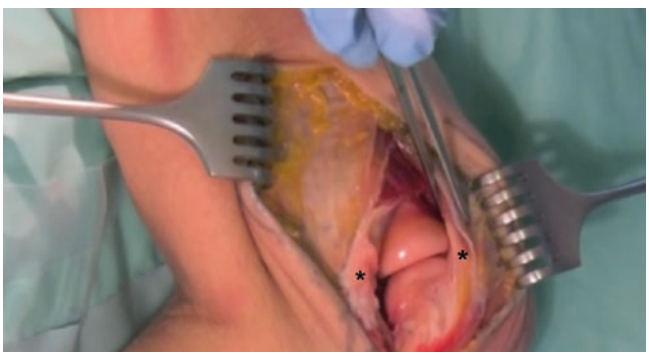


Fig. 2.12 Splitting the LCL (*), the annular ligament has been cut

2.4.3 Medial Approaches

The medial approach to the elbow is useful to explore and repair the medial collateral ligament and the medial coronoid facet and to perform internal fixation of the fractures of medial epicondyle. It is required also to perform neurolysis of ulnar nerve at cubital tunnel. The medial approach is an effective approach to treat the so-called terrible triad (Tubiana et al. 2000; Axelrod 2014).

The incision is a straight limited one, extended between the medial epicondyle and the olecranon.

The first essential step consists on the identification and protection of the ulnar nerve. It is easier to find the nerve proximal to the medial epicondyle. The surgeon has to release the ulnar nerve distally by splitting the flexor carpi ulnaris (FCU) fascia. Then, it is necessary to split the two heads of FCU. Remember that the first small branch that starts from the nerve is a sensory one to the capsule. Splitting the FCU is important to safe the first motor branch direct to the FCU itself. In Fig. 2.13, the ulnar nerve (UN) is identified proximally, and then the two heads of the FCU is splitted.

Under the medial epicondyle, it is possible to identify the medial ligament and, quite distally, the medial aspect of the proximal ulna with clear visualization of the sublime tubercle (Fig. 2.14).

A variation of classic FCU splitting approach is the so-called Hotchkiss over-the-top approach (Hotchkiss and Kasparyan 2000). This way is perfect to visualize the anterior capsule and the tip of the coronoid as presented in Fig. 2.15.

The major indication is to treat the fractures of the tip of coronoid and excision of anterior capsule in stiff elbow. To perform correctly this route, the surgeon has to identify the fibers of the brachialis muscle that run perpendicularly to flexor pronator muscles. Through the split of these muscle bellies, it is possible to visualize the anterior capsule and the tip of the coronoid. The retractors have to be placed carefully medial to the brachialis muscle, in order to not injure the brachial artery that runs just medial to this muscle. Huh et al. (2013) compared on cadaver specimen the different approaches and demonstrated that the Hotchkiss can show perfectly the tip of the coronoid and the anterior capsule, but it is not able to show the medial collateral ligament and the sublime tubercle. In conclusion, the Hotchkiss approach has small indication compared to FCU split approach (Huh et al. 2013).

Another approach, less employed and with limited indication, is the Taylor's one. It consists in an extensive dissection of the mass of the flexor digitorum superficialis and profundus and pronator teres. This approach is indicated especially for the fractures of the base of the coronoid without olecranon fracture. Shukla et al. described a modified Taylor approach with shorter skin incision and less dissection of the flexor pronator mass employed to fix coronoid base fractures and reconstruct MCL (Shukla et al. 2014).

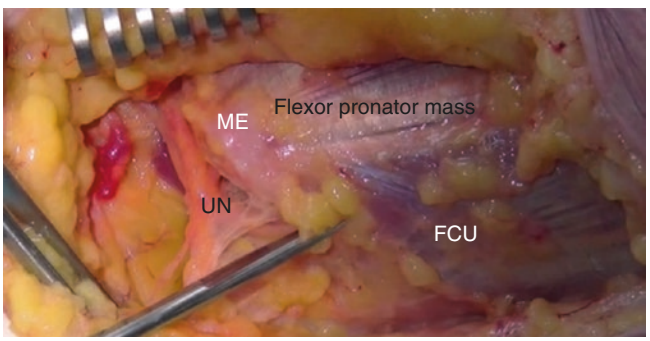


Fig. 2.13 Ulnar nerve (UN) is identified proximally, and then the two heads of the FCU are splitted

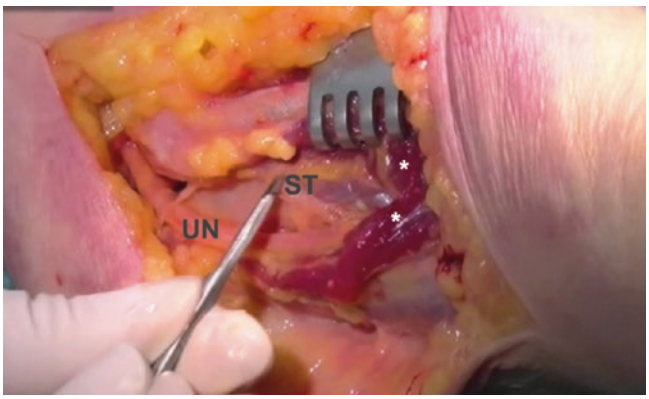


Fig. 2.14 The tip of the scissor indicates the sublime tubercle; the two heads of the FCU are splitted

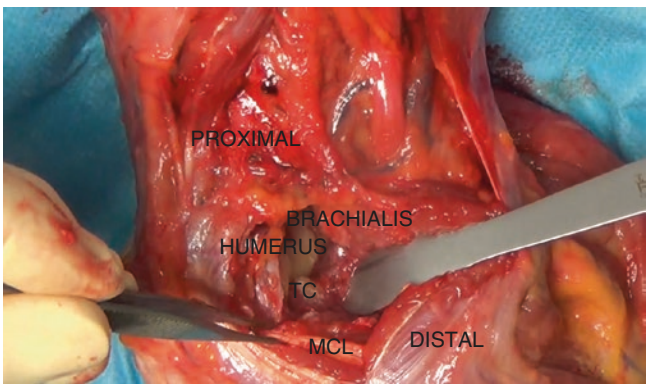


Fig. 2.15 The over-the-top approach. Through this approach, the tip of the coronoid is visualized, the MCL is intact, and the Homan's retractor is placed medial to the brachialis muscle to prevent injuries to the artery and nerve

2.4.4 Anterior Approach

The anterior approach is rarely employed to perform procedure on the joint but is frequently adopted to repair the distal biceps tendon and the release of the anterior capsule. Another frequent indication is the neurolysis of the posterior interosseous nerve (PIN) (Bauer et al. 1987).

The main landmark is the antecubital fossa. The first incision is parallel to skin groove, and then the incision could be extended proximally and distally as in an S-shaped manner. The surgeon must protect the lateral antebrachial cutaneous nerve that runs in the superficial layer between the brachialis and the biceps brachialis tendon. The median nerve and brachial artery are located medially to the biceps. Underneath the fascia, the brachioradialis and brachial muscles have to be separated. Under the muscles, it is easy to identify the bifurcation of the radial nerve in the superficial and profunda branches. Under the nerve, the radial recurrent artery and vein are present. Under the vessel's plan, the bicipitoradial bursa is present and could be followed to the radial tuberosity where the biceps tendon stops.

To completely expose the joint capsule, it is possible to interrupt the brachial muscle in the tendinous part. At this moment, the capsule is clear.

Conclusion

The elbow is a complicate anatomical district. The complication starts from the anatomy: the elbow is the cross way for different noble structures as the ulnar, median, and radial nerve. On cadaver specimen, young surgeons can appreciate the relationship that exists between the ways to approach the elbow and noble structures.The key to expose easily the elbow is to know where the nerves are, and the orthopedic surgeons have to be not scared by identification and dissection of the nerve in order to prevent any injuries as perform in medial access to the elbow where the key is to first of all dissect accurately the ulnar nerve and protect it.

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Functional Anatomy and Biomechanic Models of the Elbow

3

Marco Cavallo, Roberto Rotini, Andrea G. Cutti, and Ilaria Parel

Abbreviations

BEF	Bone-embedded frame
E	Middle point of the epicondyles
EL	Lateral epicondyle
EM	Medial epicondyle
GH	Centre of the glenohumeral joint
JCS	Joint coordinate system
RS	Radial styloid
S	Middle point of the styloid
US	Ulnar styloid
${}^{G}v_{\mathrm{FLEX}}$	Direction of the flexion-extension (FLEX) axis
${}^{G}v_{\mathrm{PS}}$	Direction of the pronation-supination (PS) axis
${}^{G}p_{\mathrm{FLEX}}$	Pivot point of FLEX axis in a global system of reference G
${}^{G}p_{\mathrm{PS}}$	Pivot point of PS axis in a global system of reference G

3.1 Introduction

It has been long debated whether to consider the elbow a complex joint or a neglected one. Both surgeons and therapists look at the elbow as a complex district that, despite high-level cares, hardly gives satisfactory results. Morrey defined the elbow as an unforgiving joint, and elbow specialists believe that healthcare professionals are often unaware of details about its biomechanics: as a result, the relative treatment cannot be adequate. Since it's not possible to make the elbow any less complex, healthcare professionals can and must act in order to improve their knowledge about this joint.

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3.2 Elbow Kinematics

The elbow has generally been described as a trocho-ginglymus joint with its complex movement divided into two components acting along different axes: flexion-extension (hinged movement of the ulna with respect to the humerus) and pronation-supination (rotatory movement of the radius with respect to the ulna). Following the nomenclature provided by the American Academy of Orthopaedic Surgeons (1966) (AAOS), the elbow's flexion-extension movement is defined as 0° in fully extended position with a straight arm, with progressive degrees of flexion while the hand gets closer to the shoulder.

The physiological ranges of motion are 145° flexion, -10° hyperextension, 75° pronation and 85° supination (Gregory et al. 2008).

In order to better understand the complex elbow kinematics, it is useful to focus on some elbow-specific anatomical features (Fig. 3.1). Firstly it is useful to point out that the articular line on the condyles has a 30° anterior rotation with respect to the long axis of the humerus (visible on the lateral view), a 5°–7° internal rotation with respect to the epycondylar line (noticeable in axial view) and a 6°–8° valgus tilt with respect to the humeral long axis (visible in frontal plane). The ulnar shaft shows a 4° valgus angulation with respect to the great sigmoid notch, which opens posteriorly with an angle on lateral view of 30°, which perfectly matches the 30° of anterior rotation of the distal humerus on the same plane. The radial head is not perfectly aligned with the long axis of the radius, showing a 15° angulation at the level of the radial neck in opposite direction with respect to the radial tuberosity (Morrey 2009; Regan et al. 1991; Alcid et al. 2004).

During the flexion-extension arch of movement, the axis of rotation (which passes through the capitellum in line with the anteroinferior aspect of the medial epicondyle) is not perpendicular to the sagittal plane of the humerus, due to the anatomical features described above. This is possible since the centre of rotation of the flexion-extension movement is not a defined single point but a variable one describing an area during the range of motion and moving about 2.5 mm

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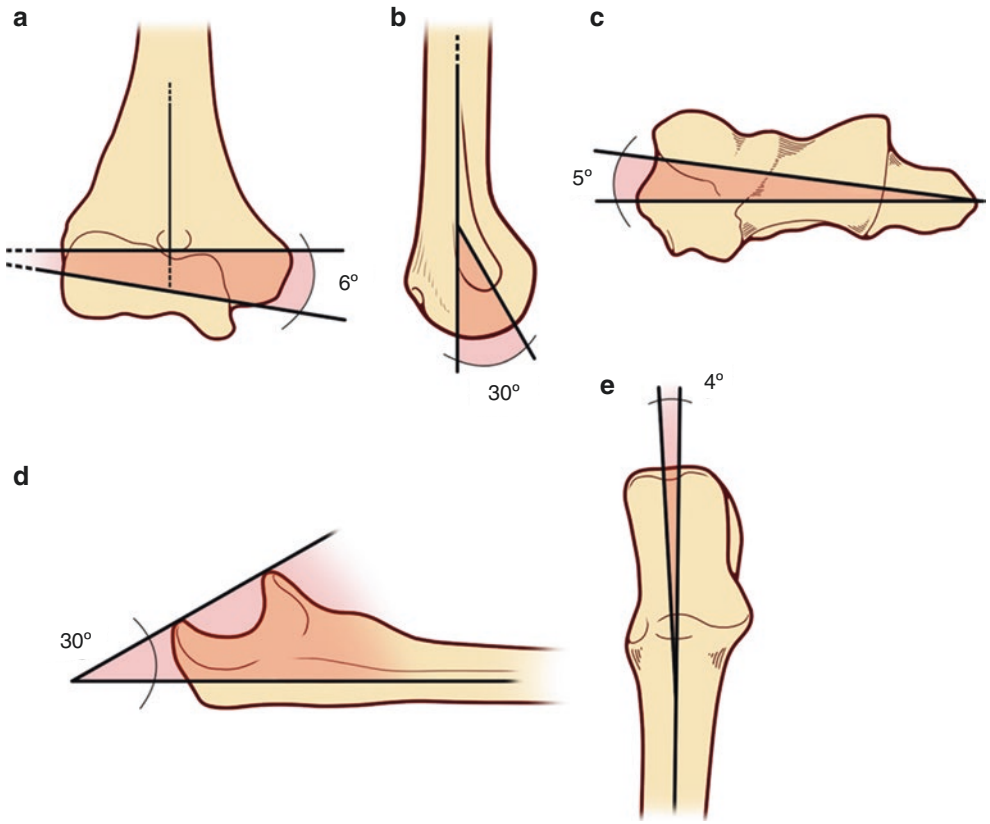


Fig. 3.1 Specific anatomical features of the elbow anatomy. The articular line on the condyles has a 6°–8° valgus tilt with respect to the humeral long axis (**a**), a 30° anterior rotation with respect to the long axis of the humerus (**b**) (visible on the lateral view) and a 5°–7° internal rotation with respect to the epycondylar line (**c**) (noticeable in axial view) (visible in frontal plane). The great sigmoid notch of the ulna opens posteriorly with an angle on lateral view of 30° (**d**) and shows a 4° valgus angulation with respect to the ulnar shaft (**e**)

medial to lateral and almost 0.8 mm anterior to posterior (Kai-Nan and Morrey 2009). It is mandatory for the clinician to consider these information, especially during external fixator positioning, for tunnel placements in reconstructive ligamentous surgery and for the proper prosthesis positioning.

These anatomical features lead to the olecranon moving on to the trochlea as a screw, causing the elbow to go from valgus position in extension to varus position in flexion. This produces the carrying angle, a phenomenon with uncertain definition as reported by Morrey (Kai-Nan and Morrey 2009). Classically described as the angle formed by the long axis of the humerus and the long axis of the ulna in full extension, with a mean value from 10° to 15° (Amis and Miller 1982; Beals 1976), it also has dynamic setting. It has also been described as an oscillatory pattern during elbow flexion (Dempster 1955), whether Morrey reported it as a linear change with maximum valgus angle in forearm full extension and diminishing during flexion. The clinical and biomechanical implications of this phenomenon are important under multiple points of view. During everyday life, in full extension, the hand is away from the body, useful in the upright position for carrying objects and loads. As the elbow flexes, the reduction of the angle allows the hand to be closer to the face, for nutrition and care (Fig. 3.2). The carrying angle variation also changes the force distribution across the distal humerus, which must be taken into account during complex reconstruction or prosthetic replacement. Inaccurate fracture

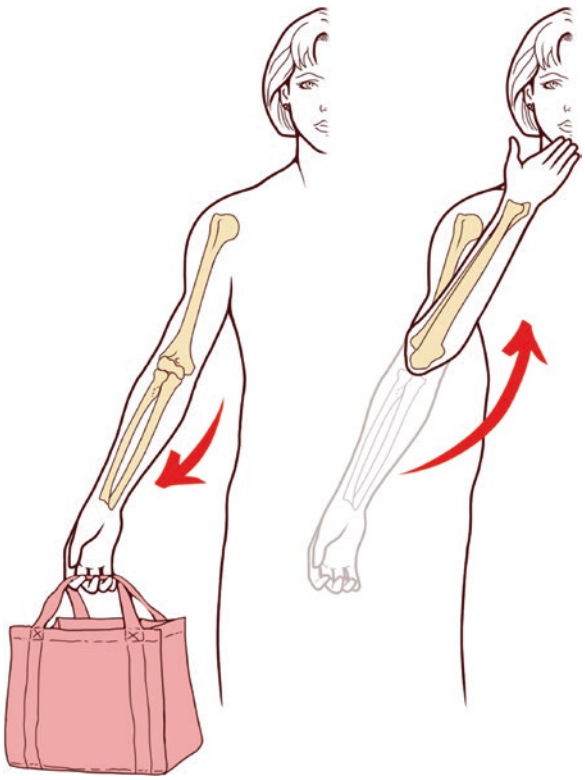


Fig. 3.2 The carrying angle is a particular feature presented by the elbow. During everyday life, in full extension, the hand is away from the body, useful in the upright position for carrying objects and loads. As the elbow flexes, the reduction of the angle allows the hand to be closer to the face, for nutrition and self-care

reduction may lead to carrying angle modification with consequent altered stress distribution and limitation of quality of life, and prosthetic designs that did not consider this phenomenon reported a high rate of early mobilization due to intense and abnormal stress on the components.

3.3 Force Transmission

The non-weightbearing configuration of the upper limb is supposed to provide less stresses on the articular structures. Once the loads are calculated and referred to the small articular surfaces and stabilizers, the stresses per surface unit are comparable to lower limb articular structures, explaining the similar material properties of these elements (such as cartilage, capsule, tendons and ligaments) in upper and lower limbs.

Elbow stability is provided by both bony and soft tissue structures, divided in primary and secondary elbow stabilizers. The primary stabilizers are composed by the humeroulnar joint, the anterior bundle of the medial collateral ligament and the lateral ulnar collateral ligament, whether the radial head, the joint capsule, the common flexor-pronator tendon and the common extensor tendon form the secondary stabilizers. These structures will be further described in the elbow instability chapter.

Because of the anatomical features of the upper limb, everyday life loads are handled at long distance from articular centre of rotation. These long lever arms are controlled by muscles, which due to their insertion being close to articular centre of rotation show small moment arms. To counterbalance this mechanical disadvantage and provide joint equilibrium, muscle tension must be scaled up; as a result forces across the joint dramatically increase, mostly not due to loads themselves but to higher muscle tension. The need of joint stability when loaded often causes antagonist muscles to compress the joint surfaces together allowing the osseous stabilizers to work properly. These actions further increase compression forces on elbow joint structures.

3.3.1 Forces During Flexion

In order to describe flexion forces, the elbow can be simplified as a structure with a load positioned around 35 cm distal to the articular axis, and the counterbalancing force provided only by the biceps tendon is positioned 5 cm distal from the axis. This requires the biceps to provide a tension which is seven times the external load in order to keep the equilibrium (Fig. 3.3).

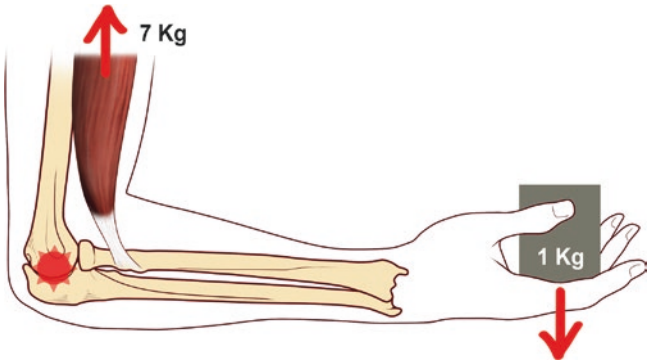


Fig. 3.3 Forces acting on the elbow in flexion can be simplified as in the figure, with a load positioned far from the articular axis and the counterbalancing force provided only by the biceps tendon, closer to the axis. This requires the biceps to provide a tension which is seven times the external load in order to keep the equilibrium and strong forces acting on the elbow as a fulcrum of the lever (type III)

Furthermore, the load acts downwards, and the biceps pulls upwards parallel to the humerus, with a net force resultance of six times the external load acting upwards on the distal end of the humerus. This schematic system is complicated by the action of several different factors: a load is usually carried by the hand, which needs to actively maintain grip by the action of multiple hand and forearm muscles flexing the fingers and stabilizing the wrist (Amis 2012; Dempster and Finerty 1947). Most of these muscle tensions cross the elbow, increasing the compression forces along the direction of the forearm. In addition, most of the muscles acting on the forearm have a rotational effect, which must be counterbalanced by their antagonists in order to keep the defined position during flexion, further increasing forces across the joint. The effects of all these muscles change at different degrees of flexion, producing a resultant force on the elbow that moves around the end of the humerus as the elbow flexes (Amis et al. 1980). In full extension, flexor muscles have a high mechanical disadvantage acting almost parallel to the forearm axis and being wrapped around the anterior joint capsule and being forced to increase their strength to provide the desired effect. This element progressively changes with flexion, reducing the muscular overstrength and consequently the compression forces across the joint from extension to flexion in a proximal and posterior direction. It has been estimated that as result of all these factors, forces on the elbow can be over 15 times greater than the external load, maximally in extended position (Amis 2012). These considerations on distal humerus are reflected on reaction forces acting on the radius and ulna. These are in a distal and posterior direction, acting on the base of the coronoid

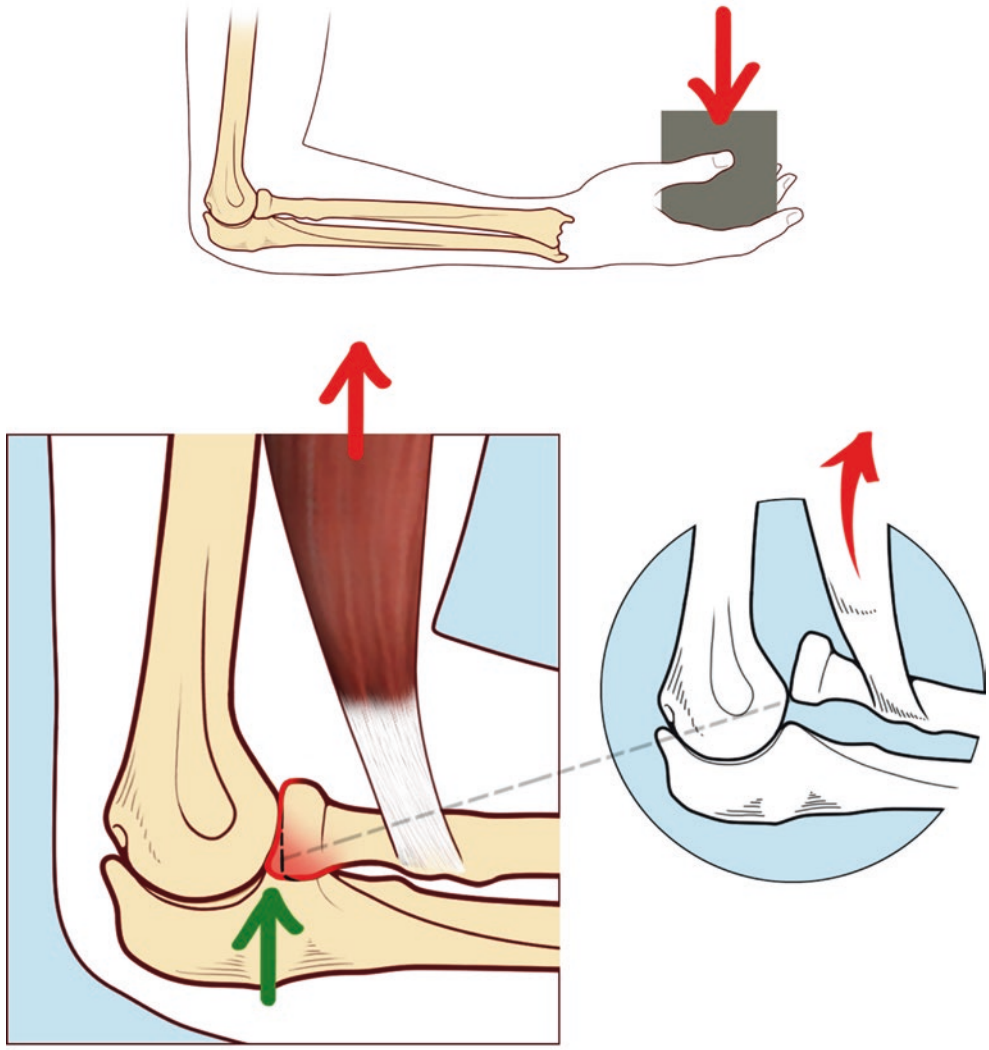


Fig. 3.4 The radial head is not circular in shape, showing an elliptical extension. This "lip" is oriented in a way that during forearm supination, it lays posteriorly to the capitulum humeri, effectively contrasting the anterior dislocating effect of the biceps, which is also maximal in supination position during object lifting

process and onto posterior lip of the concave end face of the radial head. This element is not circular, and it is oriented in a way that during forearm supination, the elliptical extension beyond the circle central area is posteriorly positioned. This means that the posterior ridge of the radial head is deepest in supination, effectively contrasting the anterior dislocating effect of the biceps, which is also maximal in supination position (Fig. 3.4). The annular ligament provides further stabilization towards this effect. Conversely, during falls with the forearm extended and internally rotated, the radial head elliptical lip is positioned anteriorly, providing supplemental anatomical barrier to the posterior radial head dislocation (Fig. 3.5). These concepts must be kept into high consideration in radial head replacement, in order to maximize the benefit of the procedure and the long-term outcome: since the radial head prosthesis has a circular shape, the supplemental stabilization effect is lost, increasing the importance of a valid and tightened annular ligament, which is mandatory to accurately reconstruct.

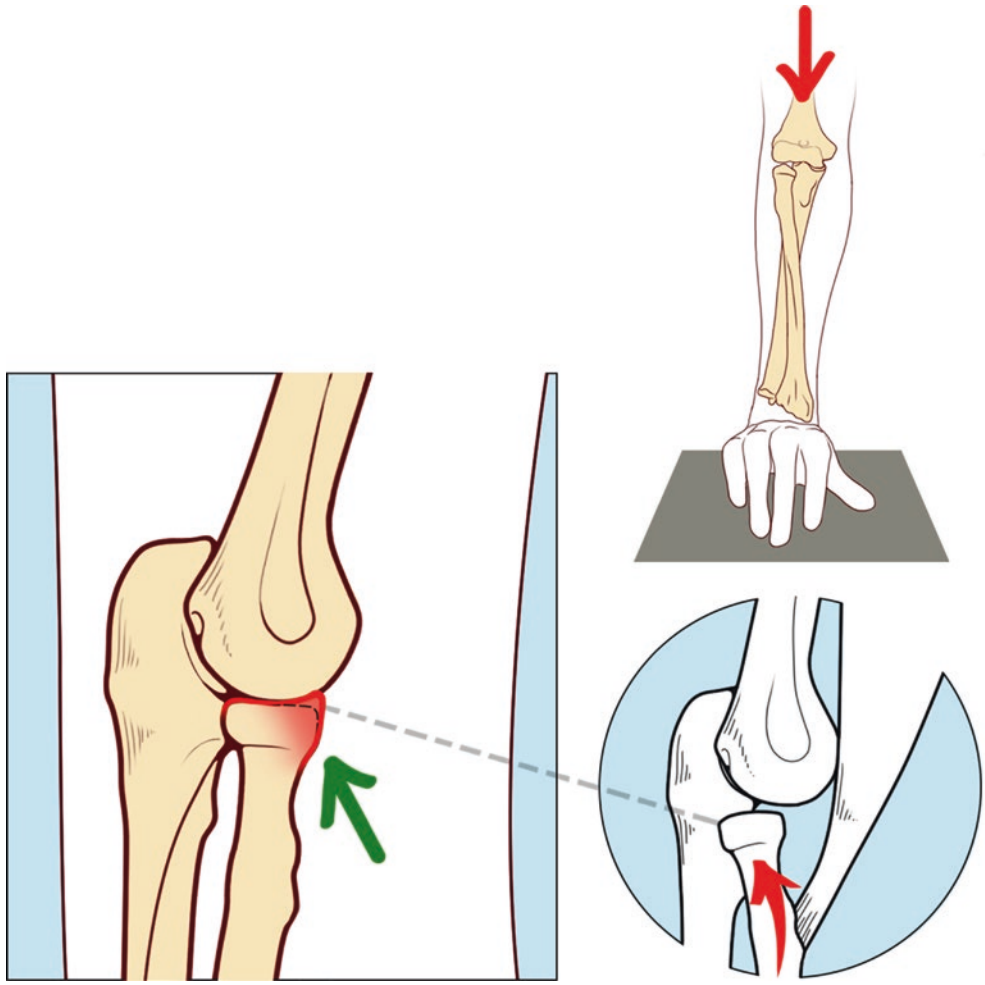


Fig. 3.5 In elbow pronation position, with the forearm extended and internally rotated, the radial head lip is positioned anteriorly to the capitulum humeri. This is particularly important during falls, when forces are directed posteriorly, and the radial head lip provides supplemental anatomical barrier to the posterior radial head dislocation

3.3.2 Forces During Extension

Active elbow extension is provided almost entirely by triceps, especially its medial head, with a small contribution from the anconeus muscle. The majority of the load bears on the humero-ulnar joint, with a small amount on the radiocapitellar joint. The forearm muscles used to stabilize the wrist and flex the fingers to grip an object increase the forces across the joint, along with the stabilizing activity of the biceps, estimated to be 7% of the triceps tension (Messier et al. 1971). During active extension from a flexed position, the elbow forces are very intense since the triceps tendon wraps around the olecranon and trochlea, with a small moment arm of around 2 cm. It follows that to overcome this mechanical disadvantage, the forces need be 20 times greater than the load at the hand. This carries out how clinically important it is to obtain secure fixation of the olecranon after fractures or osteotomies and that it is mandatory to preserve as much olecranal bone stock as possible during replacement in order to not reduce its tensile strength.

3.3.3 Forces During Forearm Rotation

Only small forearm muscles act transversely between the ulna and radius, with a small component of the larger muscle activity. This means that forces on radio-ulnar joints are relatively small compared to the axial loads. The hand and wrist muscles provide axial compressive forces that help maintaining the congruence of the radiocapitellar joint.

3.3.4 Forces During Abduction and Adduction

The major forces during elbow adduction are developed with 90° of flexion and the shoulder internally rotating, i.e. the action of closing a door. The reaction forces, again increased by the length of the forearm and the unfavourable mechanic moment, are carried out by the MCL in distraction (for six times the external load) and for the radial head compressing onto the capitellum (for eight times the load) (Amis 2012)

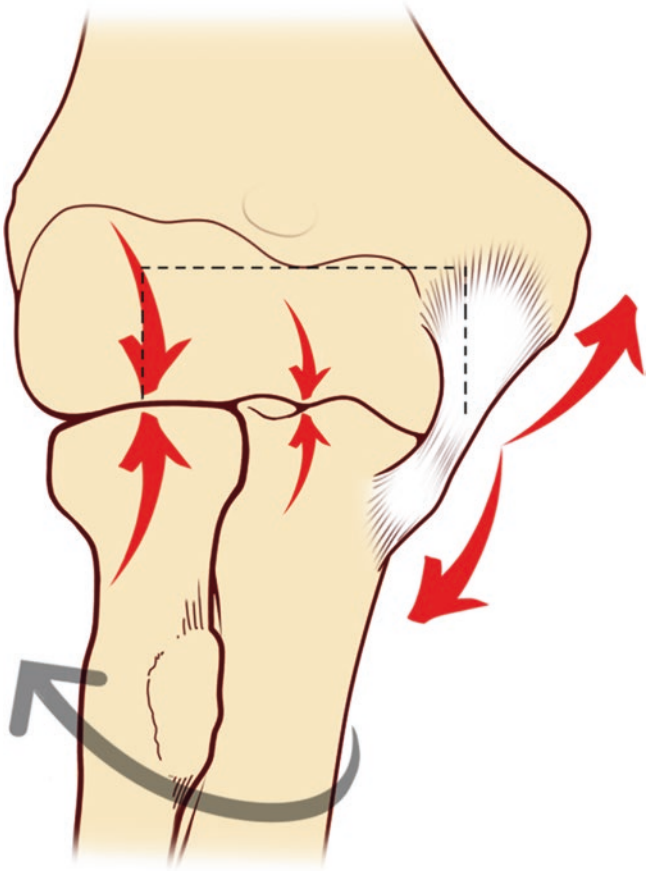


Fig. 3.6 In shoulder rotatory movements against resistance like closing a door, the flexed elbow is crossed by different reaction forces. These are carried out by the MCL in distraction and by the radial head in compression onto the capitellum as the most lateral part of the elbow joint (see *dashed line*), with a small component acting on the coronoid process

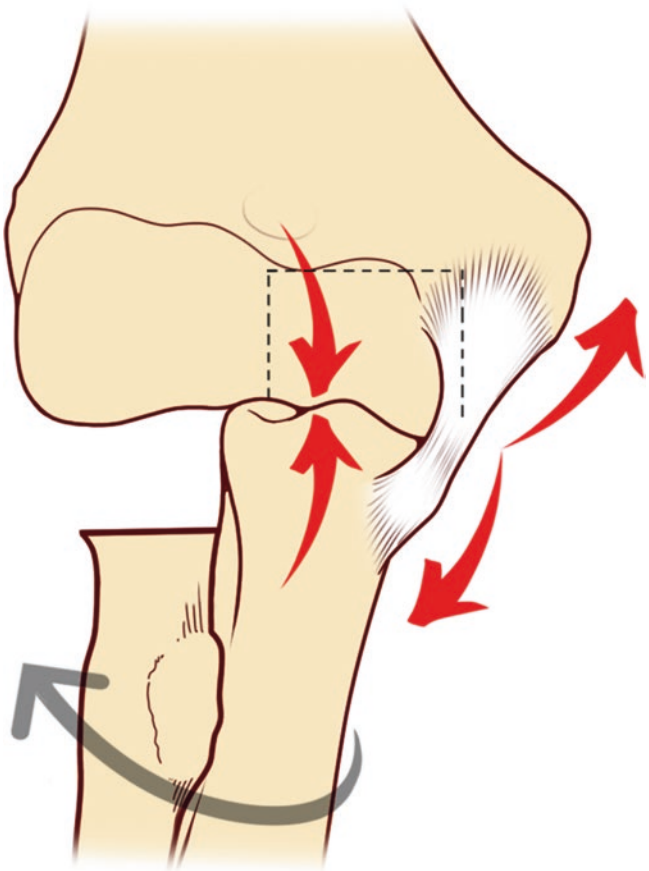


Fig. 3.7 In case of radial head resection, the forces in compression develop on the lateral portion of the coronoid process (see *dashed line*). The lever arm is less favourable than in the presence of the radial head, leading to an increase of the force entity. This overload may be responsible to humero-ulnar arthritis development in the long term

(Fig. 3.6). In case of radial head resection, the forearm's base width on distal humerus is reduced, with an increase of the forces acting on the lateral facet of the coronoid process that must counterbalance the torque of the MCL tension. Since the distance between MCL and lateral facet of the coronoid is smaller than the distance between the MCL and radial head, in case of radial head resection, the forces are much higher, often leading to an increase valgus of the elbow (Taylor and O'connor 1964) (Fig. 3.7).

3.3.5 Force Transmission During Falls

Studies report that with elbow extended, 60% of the load applied to the hand is transferred to the capitellum through the radial head, while 40% is passed to the trochlea through the coronoid process (Halls and Travill 1964) (Fig. 3.8). In case the radial head prosthesis is excessively thick, this equilibrium is altered, offloading the coronoid and damaging the capitellar surface (Markolf et al. 2004).

During falls, on outstretched hand in order to place the palm down on the floor, the typical posture has the forearm partially pronated, the elbow flexed at around 15° and the shoulder flexed, abducted and internally rotated. The partial flexion of the elbow allows for a force dissipation with triceps contraction during elbow forced flexion, reducing the load on the bones and preventing fractures that are more frequent in case of fully extended elbow. The combination of axial compression and valgus moment on the forearm during these falls may cause fracture of the radial head: because of the tension on the MCL, the load on the radio-capitellar joint is larger than the external load, while the coronoid process may be unloaded, until the radial head is intact (Amis et al. 1981).

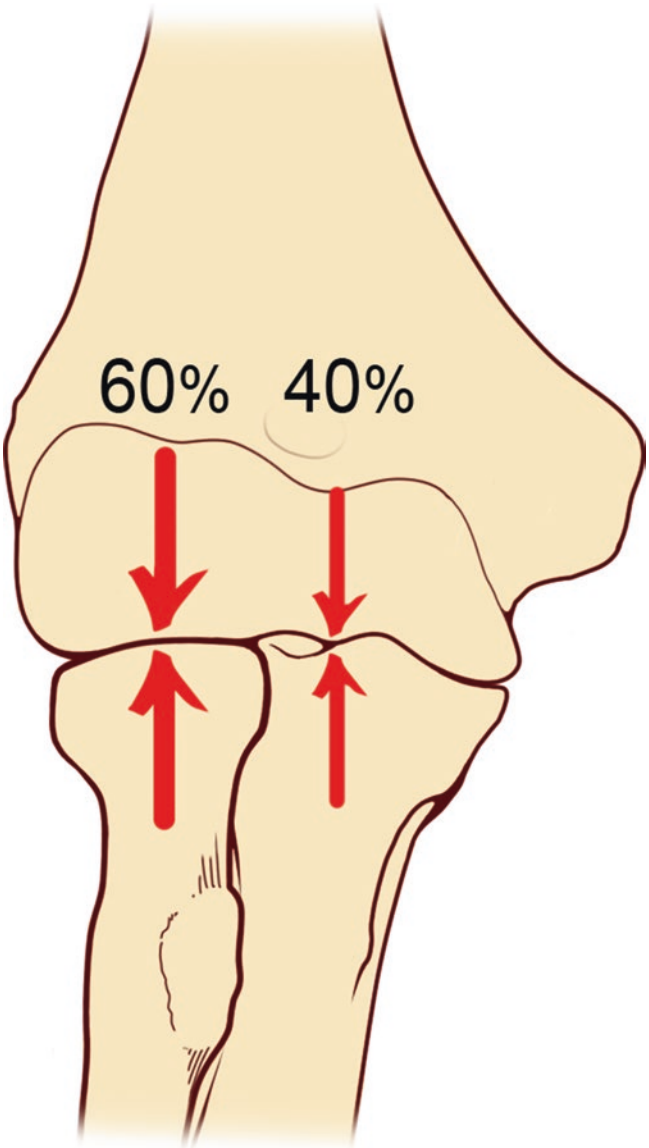


Fig. 3.8 In extended position, the load applied to the hand is transferred for 60% to the capitellum through the radial head while for 40% to the trochlea through the coronoid process

3.4 Biomechanical Models of the Elbow

Cadaver studies (Veeger et al. 1997) showed that the elbow can be modelled with two hinge joints, the first describing the rotation of the ulna and radius with respect to the humerus (flexion-extension) and the second describing the complex movement of the radius around the ulna, i.e. an elusive movement of the ulna around the radius (pronation-supination). The flexion-extension and pronation-supination axes are not concurrent in a single point and are only roughly orthogonal, with intersubject variability. This stresses the importance of subject-specific biomechanical models, obtained through dedicated kinematic approaches as summarized in Kontaxis et al. (2009).

With this chapter, we want to make evident how excessive simplification of elbow kinematics can lead to erroneous functional assessment of patients and wrong parameters for the construction of prostheses for joint replacement. For this purpose, alternative modelling approaches are presented, and results are compared and reviewed in a clinical perspective. Great attention is given to the interpretation of the carrying angle, with a distinction between the anatomical and the functional/biomechanical definition.

3.5 Introduction

In 2005 the International Society of Biomechanics (ISB) realized recommendations for the description of joint kinematics at the upper extremity (Wu et al. 2005), based on the definition of the Joint Coordinate Systems (JCSs), following Grood and Suntay (1983). The JCS of a joint is built based on two coordinate systems, one for each bone forming the joint, each named "bone-embedded coordinate system" or "bone-embedded frame (BEF)". The description of joint kinematics, not considering the intra-joint translation problem, is thus obtained by interpreting the relative orientation of the distal with respect to the proximal BEF as a sequence of angles, through a predefined Euler decomposition. In this process, the axes of rotation of the joint are assumed to be coincident with the axes of the BEFs. However, since BEFs are commonly defined from the position of well-identifiable anatomical landmarks, their axes are only *approximations* of the real joint rotation axes. Considering the elbow, the ISB proposed two different BEFs for the humerus (H1 and H2) and one for the forearm (F1). In addition, the International Shoulder Group (ISG) proposed an alternative definition of forearm BEF, named herein as F2.

The BEF described so far does not consider the evidence provided by Veerger (Veeger et al. 1997) that the pronation-supination and the flexion-extension axes of rotation of the elbow are roughly perpendicular. It might be *possible* (and we will evaluate if really *desirable* later in the chapter) to use anatomical landmarks and further constrain the orientation of the medio-lateral axis of the proximal humerus to the long axis of the forearm, giving rise to a further humerus-embedded frame named herein as Hv.

A completely different approach in defining BEF is represented by the so-called functional approach (Stokdijk et al. 2000; Biryukova et al. 2000). This consists in the estimation of the flexion-extension and pronation-supination axes of

rotation of the joint for each single subject under assessment, who is asked to actively or passively move the joint one degree of freedom at a time, for a few seconds. These movements will be referred herein as "pure movements" of flexion-extension and pronation-supination, respectively. Using the data acquired during pure movements, the mean axes of rotation can be estimated by applying, for example, the algorithm proposed by Woltring (1990). Alternatives can be, for example, the algorithms by Halvorsen et al. (1999) or Gamage and Lasenby (2002). The estimation of the position and orientation of these axes is then directly used to build the BEF, without assumptions on the specific relationships of the axes with anatomical landmarks. The functional approach for the elbow appears very appealing for the elbow based on cadaver studies (Veeger et al. 1997) that showed that the elbow can be reasonably modelled with two hinge joints with the axes not concurrent in a single point. The application of the functional approach gives rise to a functional frame for the humerus (Hw) and one for the forearm (Fw).

A question naturally arises: given the multiple options available for modelling, which are the differences in kinematics? In other terms, will a patient look similar or dissimilar when the different methods are used to collect treatment outcomes and which is the best modelling? The aim of this chapter is to try to answer these questions, using two biomechanical models of the elbow obtained from cadaver data (Veeger et al. 1997).

3.6 Joint Coordinate Systems

The ISB recommends the use of two different systems of reference for the humerus, namely, H1 and H2 (Table 3.1). For both, the elbow flexion-extension is represented by the *x*-axis. In H1, x_{H1} is only based on ^{G}GH, ^{G}EL and ^{G}EM, and its orientation is determined by the correct location of ^{G}EL and ^{G}EM (Wu et al. 2005). For this reason, ISB introduced H2 as an alternative, where X_{H2} is normal to the long axis of the humerus and forearm when the elbow is flexed 90° and completely supinated (this will be referred hereinafter as the H2 definition pose). While the computation of H1 is straightforward from the data reported in Veeger et al. (1997), the computation of H2 requires the knowledge of the global coordinates of ^{G}US and ^{G}RS in its definition pose (Cutti et al. 2006a, b).

For the forearm, the ISB adopted the system of reference named F1 (Table 3.1), where the pronation-supination axis direction is from US to the middle point of the epicondyles *E*. In previous recommendations, the ISG recommended F2, where the pronation-supination axis direction is from *S* (middle point of the styloids) to *E*. All the systems of reference considered so far (H1, H2, F1 and F2) are only based on anatomical landmarks (Fig. 3.9).

Table 3.1 Definition of all the bone-embedded reference frames considered

Segment	Axes definition
Humerus H1	$Y_{H1} = (GH - E)/\|\|(GH - E)\|\|$: longitudinal
	$Z_{H1} = Y_{H1} \wedge (EM - EL)/\|\|Y_{H1} \wedge (EM - EL)\|\|$: anteroposterior
	$X_{H1} = Y_{H1} \wedge Z_{H1}$: medio-lateral
	Origin = GH
Humerus H2	$Y_{H2} = (GH - E)/\|\|(GH - E)\|\|$: longitudinal
	$X_{H2} = Y_{H2} \wedge (E - US)/\|\| Y_{H2} \wedge (E - US)\|\|$: medio-lateral
	$Z_{H2} = X_{H2} \wedge Y_{H2}$: anteroposterior
	Origin = GH
Humerus Hw	$Y_{TEMP} = (GH - E)/\|\|(GH - E)\|\|$: longitudinal
	X_{HW} = estimated applying a functional method during pure flexion-extension movements, e.g. (Woltring (1990)) medio-lateral
	$Z_{HW} = X_{HW} \wedge Y_{HW}$: anteroposterior
	$Y_{HW} = Z_{HW} \wedge X_{HW}$: longitudinal
	Origin = *E*
Humerus Hv	$Y_{F} = (E - US)/\|\|(E - US)\|\|$
	$Z_{HV} = Z_{H1}$: anteroposterior
	$X_{HV} = Y_{F} \wedge Z_{H1}$: medio-lateral
	$Y_{HV} = Z_{HV} \wedge X_{HV}$: longitudinal
	Origin = GH
Forearm F1	$Y_{F1} = (E - US)/\|\|(E - US)\|\|$: longitudinal
	$Z_{F1} = (RS - US) \wedge Y_{F1}/\|\|(RS - US) \wedge Y_{F1}\|\|$: anteroposterior
	$X_{F1} = Y_{F1} \wedge Z_{F1}$: medio-lateral
	Origin = *E*
Forearm F2	$Y_{F2} = (E - S)/\|\|(E - S)\|\|$: longitudinal
	$Z_{F2} = (RS - US) \wedge Y_{F2}/\|\|(RS - US) \wedge Y_{F2}\|\|$: anteroposterior
	$X_{F2} = Y_{F2} \wedge Z_{F2}$: medio-lateral
	Origin = *E*
Forearm Fw	Y_{Fw} = estimated applying a functional method during pure pronation-supination movements, e.g. (Woltring, 1990) longitudinal
	$Z_{Fw} = (RS - US) \wedge Y_{Fw}/\|\|(RS - US) \wedge Y_{Fw}\|\|$: anteroposterior
	$X_{Fw} = Y_{Fw} \wedge Z_{Fw}$: medio-lateral
	Origin = *E*

Table 3.1 also reports the definition of Hv, which is based on anatomical landmarks, and constrains the flexion-extension axis of rotation to be perpendicular to the pronation-supination axis estimated based on anatomical landmarks as in F1.

Differently from the approach described so far, two alternative coordinate systems can be defined exploiting the functional (motion-based) estimation of the axes of the joint, as anticipated in the Introduction. Table 3.1 specifies one functional coordinate system for the humerus (Hw) and one for the forearm (Fw).

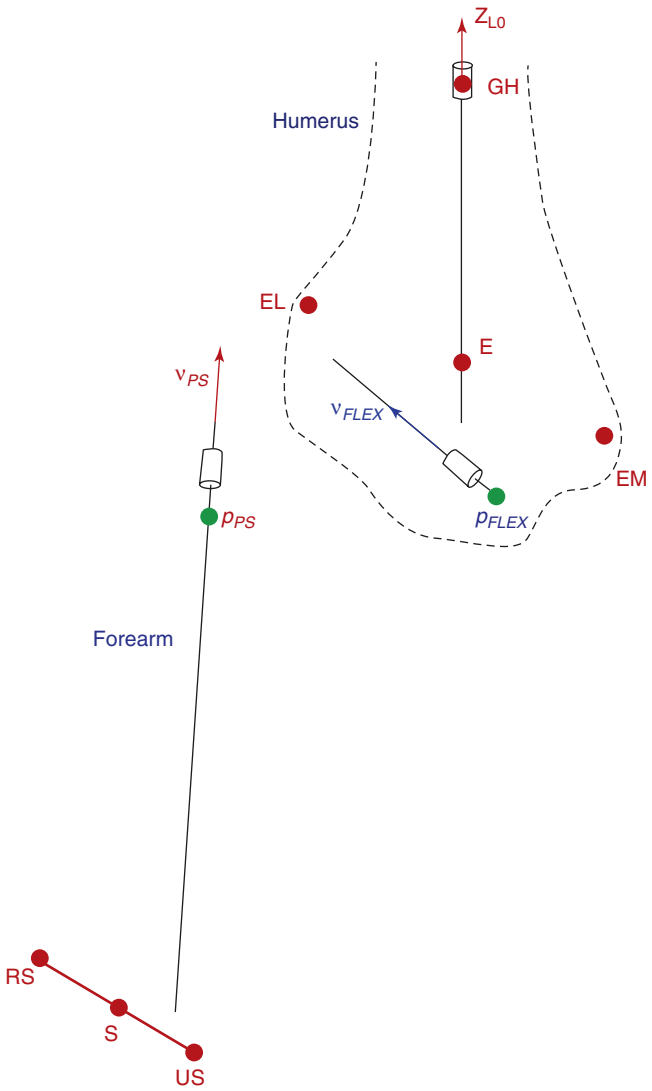


Fig. 3.9 Scheme of landmarks for the reconstruction of elbow reference models

3.6.1 Comparison of Different Joint Coordinate Systems

Two computer models, based on cadaver data reported in Veeger et al. (1997), were generated using MATLAB® (Cutti et al. 2006b). For each computer model, the coordinate systems were computed, and starting from the anatomical posture, a pure 140° elbow flexion-extension movement was simulated while keeping a full pronation.

For this work, the following JCS-based kinematics were then computed:

$$^{H1}R_{F1} = \left({}^{G}R_{H1} \right)^{T} \cdot {}^{G}R_{F1} \tag{3.1}$$

$$^{H2}R_{F1} = \left({}^{G}R_{H2} \right)^{T} \cdot {}^{G}R_{F1} \tag{3.2}$$

$$^{H1}R_{F2} = \left({}^{G}R_{H1} \right)^{T} \cdot {}^{G}R_{F2} \tag{3.3}$$

$$^{Hw}R_{Fw} = \left({}^{G}R_{Hw} \right)^{T} \cdot {}^{G}R_{Fw} \tag{3.4}$$

$$^{Hv}R_{F1} = \left({}^{G}R_{Hv} \right)^{T} \cdot {}^{G}R_{F1} \tag{3.5}$$

Figure 3.10 reports the patterns obtained from both models with the simulation completed considering the forearm in full pronation.

Starting from a qualitative observation of the results, it appears that the only JCS able to exactly reproduce the imposed joint kinematics is $^{Hw}R_{Fw}$, since this embeds the knowledge about the real axes of flexion-extension and pronation-supination. While the error of estimation for flexion-extension is usually limited between 3% and 4% of the range of motion (worst case for S2: 4.54° for $^{H2}R_{F1}$; worst case for S4: 5.56° for $^{Hv}R_{F1}$), the greatest differences appear in the carrying angle and pronation-supination patters. The carrying angle is usually defined as the angle between the long axis of the humerus and the forearm (Zatsiorsky, 1998). From this point of view, the patterns reported by $^{H1}R_{F1}$, $^{H2}R_{F1}$ and $^{H1}R_{F2}$ appear consistent with the expectations. In particular, for $^{H1}R_{F2}$, adhering the most to the usual definition, the reported values are close to expectation. The values obtained from $^{H1}R_{F1}$ and $^{H2}R_{F1}$ are instead slightly different from those usually reported in the literature, due to a different definition of the long axis of the forearm. From a strictly robotics point of view, however, the only correct results are those obtained from $^{Hw}R_{Fw}$. The carrying angle value is, in fact, a measure of intrinsic parameters of the biomechanical models (interpreted here as robots) that cannot be assimilated from any point of view to a degree of freedom and that do not change with time. *In particular, the carrying angle is a measure of the relative orientation of the flexion-extension and pronation-supination axes*. We cannot therefore speak about a carrying angle imposed on the model; we can just see in it the evidence of a serial link construction parameter. From an anatomical point of view, we can interpret this consideration thinking about *the carrying angle* from $^{Hw}R_{Fw}$ as a *measure of the internal morphology of the joint*. For what concerns $^{Hv}R_{F1}$, the results reported for S2 closely resemble the gold standard. Unfortunately, $^{Hv}R_{F1}$ returns a completely wrong pattern for S4, due to a wrong estimation of the flexion-extension axis (see Fig. 3.10).

All JCS reported a *non*-null pronation-supination range, with the exception of $^{Hw}R_{Fw}$ which correctly estimates the gold standard in range and absolute value. In particular, $^{H1}R_{F1}$ and $^{H2}R_{F1}$ reported a range of pronation-supination ranging from 11.5° to 16°. Results are not better for $^{H1}R_{F2}$, with a range from 12° to 15°. $^{Hv}R_{F1}$ performs better than the others for S2 (9°) but it is the worst for S4 (18°). The reported errors are of great magnitude and suggest *a careful interpretation*

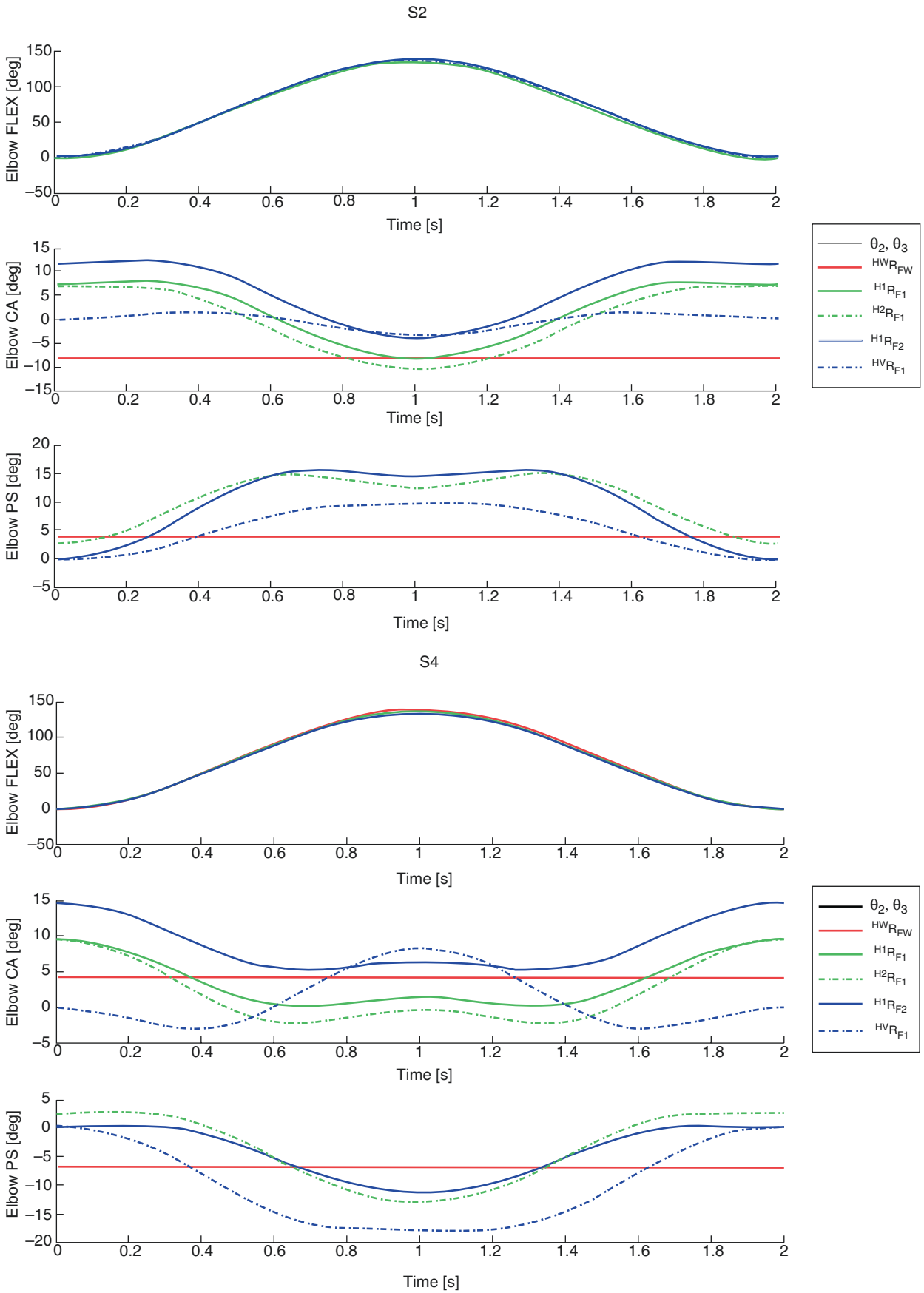


Fig. 3.10 Kinematics estimated by the different JCS considered, compared to the imposed motion. The gold standard patterns (*black*) are not visible since it is completely overlapped by ${}^{Hw}R_{Fw}$ estimation

of in vivo *kinematic data, in particular those related to complex activities of the daily living*. It should be noticed that the errors reported are not limited to a particular range of initial pronation-supination but always exist.

3.7 Conclusion

In conclusion, results for the ISB-recommended JCS (${}^{H1}R_{F1}$ and ${}^{H2}R_{F1}$) show that kinematic data should be interpreted with caution. While the error in the estimation of the flexion-extension appears acceptable, those reported for pronation-supination may deeply affect the analysis of complex movements of the daily living: an error ranging from 11.5° to 16° cannot in fact be neglected, being comparable to voluntary movements of the subject. This artefact movement may also affect the estimation of net moments and powers of the upper extremity. The use of ${}^{Hw}R_{Fw}$, on the other hand, always provides optimal results. *Moreover, it helps, in the author's opinion, to interpret more correctly the meaning of carrying angle.* The main disadvantage of ${}^{Hw}R_{Fw}$ is that for its definition, the estimation of the elbow flexion-extension and pronation-supination axis is required. However, this can be easily done for most patients, asking them to perform pure flexion-extension and pronation-supination movements. Results reported in the literature are promising. Even passive movements are possible, guided by the operator. For those patients who cannot perform pure movements, ISB recommendation remains the best choice. Therefore, we would suggest to use ${}^{Hw}R_{Fw}$ in parallel to ISB definition, for a clearer interpretation of results. In particular, it can be considered to associate H1 (or H2) to the proximal humerus and Hw to the distal humerus. *H1 (H2) will therefore be used for the description of the glenohumeral ball and socket joint, which does not prescribe preferred motion axes, while Hw will be used for describing, with Fw or F1, the motion of the elbow joint, where preferential motion axes exist.*

This approach to kinematic description finds an analogue in robotics in Litvin's definition of systems of reference (Litvin 1975, 1980). Moreover, the use of functional methods for joint axes determination appears coherent with the ISB suggestions for joint centre estimation, where functional methods proved to be superior to regression equations based on palpation.

3.8 Biomechanical Take-Home Messages for the Clinical Practice

An accurate evaluation of the biomechanics of the elbow is fundamental for the clinical practice. The physiological ranges of motion of the elbow are 145° flexion, -10° hyperextension, 75° pronation and 85° supination (Gregory et al. 2008). A proper estimation of flexion-extension and pronation-supination axes has been demonstrated to be essential for the assessment of elbow functioning. The medical professional should be aware of the methodology applied for the measurement or should consult a biomechanist to scrutinize the methodology applied in commercial products.

It is important to remember that the flexion-extension axis of the elbow is typically rotated with respect to the long axis of the humerus as shown in Goto et al. (2004): about 12° in the frontal plane and 11° in the transverse plane. The distance between flexion-extension and pronation-supination axes is between 4 and 8 mm. The elbow can be reasonably described as a double-hinge joint with nonintersecting axes of rotation. This is consistent with what is reported by Amis (Amis 2002). A difference should be made between the anatomical carrying angle and the actual biomechanical (or functional) carrying angle. The former is a purely exterior description and is traditionally measured between the long axis of the humerus and the ulna, when the elbow is completely extended and supinated, and decreases with elbow flexion. In this position, the value of the CA varies between 10° and 15° (mean 12°), usually larger for women than for men. The actual, essential biomechanical carrying angle is a (almost) constant parameter and previously shown in the literature. This angle does not change because both the flexion-extension and pronation-supination axes have a constant relative orientation, even during elbow movements (flexion-extension and pronation-supination).

The use of suboptimal kinematic models leads to a misinterpretation of the carrying angle and of pronation-supination. This is detrimental when designing prostheses for joint replacement, because the prosthesis will try to impose a non-physiological motion and might ultimately deteriorate or mobilize. Misunderstanding of these concepts is also detrimental for the assessment of patients' outcome, because treatment comparisons will be falsified by a wrong modelling.

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Clinical Examination and Scores

4

Davide Blonna and Filippo Castoldi

The physical examination of the elbow is a fundamental tool in the diagnosis of elbow disorders. Associated with a detailed patient history, it can provide most of the information the physician needs to make proper diagnosis and treatment decisions.

After the description of the general examination of the elbow, we will discuss the tests for the specific elbow disorders. These tests have to be performed correctly in order to be effective and preserve their accuracy. Then we will discuss the most important rating systems for elbow evaluation.

Even though not described in this chapter, the examiner has to remember to perform a meticulous evaluation of the structures both proximal and distal to the elbow. The examination of the elbow will be incomplete without an assessment of the cervical spine (the main nerve roots involved with elbow function are C5-7), of the shoulder (e.g. a loss of internal rotation has been reported among athletes with medial collateral ligament insufficiency (Dines et al. 2009)) and of the wrist (an injury to the interosseous membrane or to the distal radio-ulnar joint must be ruled out).

4.1 Visual Assessment

The physical examination of the elbow always starts with an accurate visual assessment of both the affected and the contralateral elbows. Since subcutaneous tissue is scant, bony alterations, soft tissue swelling and muscle atrophy can be usually appreciated with ease.

Angular deformities are easy detectable and must be compared to the contralateral side (Fig. 4.1).

The carrying angle is determined by asking the patient to externally rotate the shoulder, to supinate the forearm and the hand and to maximally extend the elbow: in case of flexion contracture, the carrying angle can be difficult to assess, and it has been demonstrated that it linearly decreases with flexion (Morrey and Chao 1976). Hence, it should not be assessed on radiographs. The average values are from 11° to 14° in men and from 13° to 16° in women (Paraskevas et al. 2004; Keats et al. 1966). The difference between male and females could be caused by the increased joint laxity in women which permits a greater degree of extension (Beals 1996). The carrying angle is usually assessed with a goniometer, even if some authors have described that the electrogoniometer provides more reliable results than other methods (Zampagni et al. 2008). Yilmaz et al. measured the elbow carrying angle on the dominant and non-dominant extremity. The carrying angle of the dominant arm was found to be significantly



Fig. 4.1 A young patient showing her left elbow affected by significant cubitus valgus

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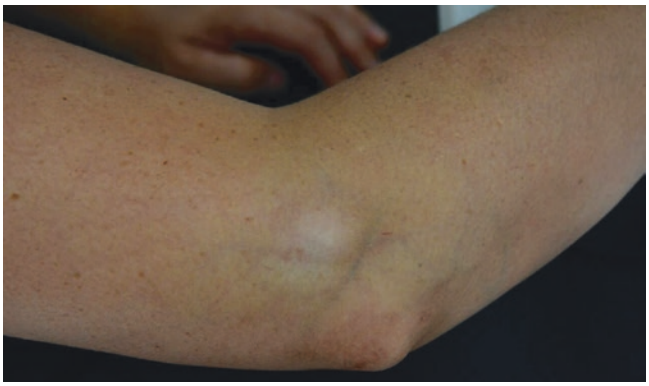


Fig. 4.2 Skin depigmentation around the lateral epicondyle following corticosteroid injections

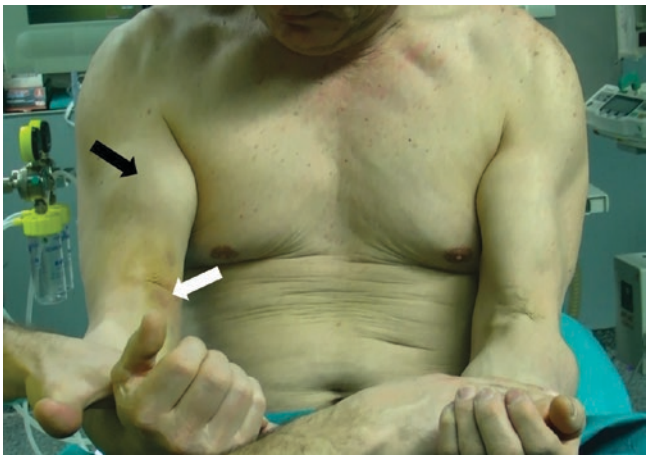


Fig. 4.3 Patient affected by distal biceps tendon rupture. The *black arrow* indicates the proximal shift of the muscle's belly. The *white arrow* indicates the anterior ecchymosis

higher than the non-dominant (approximately 1° different), both in men and women; patients over 14 years old showed a higher carrying angle both of the dominant and non-dominant arms than that shown by younger patients (Yilmaz et al. 2005). However, Sharma et al. have recently shown in their study that the carrying angle was greater in the non-dominant arm than in the dominant arm (Sharma et al. 2013).

Then attention should be paid to the lateral recess, the epicondyles, the antecubital fossa and the olecranon tip.

The lateral recess is also called the "soft spot" and is the area between the radial head, the lateral epicondyle and the tip of the olecranon. In case of an increase in synovial fluid or haemarthrosis, it is usually swollen.

Medial or lateral ecchymosis may suggest fractures of the epicondyles or collateral ligament tears, while skin depigmentation may indicate previous multiple corticosteroid injections (Fig. 4.2). Moreover, ulnar nerve subluxation may be visible medially (Childress 1975).

Anterior ecchymosis and alteration of the biceps muscle belly can occur subsequent to distal biceps tendon rupture (Fig. 4.3). Posterior swelling may suggest triceps avulsion, olecranon fracture or olecranon bursitis. Rheumatoid nodules or gout tophi can be appreciated on the subcutaneous border of the ulna, and examination of the extremities can be helpful (Fig. 4.4).

Key Points

The carrying angle ranges between 11° and 14° in men and between 13° and 16° in women.

The "soft spot" is usually swollen in cases of synovial fluid increase or haemarthrosis.



Fig. 4.4 Patient affected by gout

4.2 Palpation

The main structures to be palpated are the following:

- Both the epicondyles and the tip of the olecranon: tenderness on palpation may suggest "golfer elbow", "tennis elbow" or triceps tendon disease.
- The medial collateral ligament (MCL): tenderness along its course can be appreciated with the elbow in 30° to 60° of flexion; it has an 81% to 94% sensitivity but only a 22% specificity for MCL tears (Thompson et al. 2001; Timmerman et al. 1994). The point of tenderness is about 2 cm distal to the medial epicondyle.
- The cubital tunnel: the ulnar nerve is easily appreciated in the groove behind the medial epicondyle. The Tinel sign (which should be compared with the contralateral side) may suggest its entrapment; its sensitivity ranges between 54% and 70%, and its specificity ranges between 53% and 99% (Novak et al. 1994; Cheng et al. 2008; Beekman et al. 2009).
- The olecranon bursa: thickening, pain and sometimes bony spurs can be detected.
- The radial head: it is easily palpated combining flexion at several degrees with pronation and supination.
- The arcade of Fröhse: the region where the posterior interosseous nerve enters the supinator muscle (the nerve rests on the deep head of the supinator); it is located around 2 cm anterior and 3 cm distal to the lateral epicondyle.
- The distal biceps tendon: it is palpated by asking the patient to fully supinate his/her forearm. It is important to distinguish the lacertus fibrosus from the distal biceps tendon in order to avoid missed diagnosis of distal biceps tendon rupture (Fig. 4.5).

Key Point
The main structures to be palpated are the epicondyles, the ulnar nerve, the olecranon bursa, the radial head, the arcade of Fröhse, the lacertus fibrosus and the distal biceps tendon.

4.3 Range of Motion (ROM) Evaluation

Since the function of the elbow is to position the hand in the space, one of the main aspects of the physical examination of the elbow is the correct assessment of the ROM.

The standard position for a correct evaluation has been suggested by O'Driscoll (Blonna et al. 2012). The patient is asked to stand upright and flex the shoulder to 90°. Extension is measured with the elbow extended as fully as possible with the palm of the hand facing the ceiling in full supination.

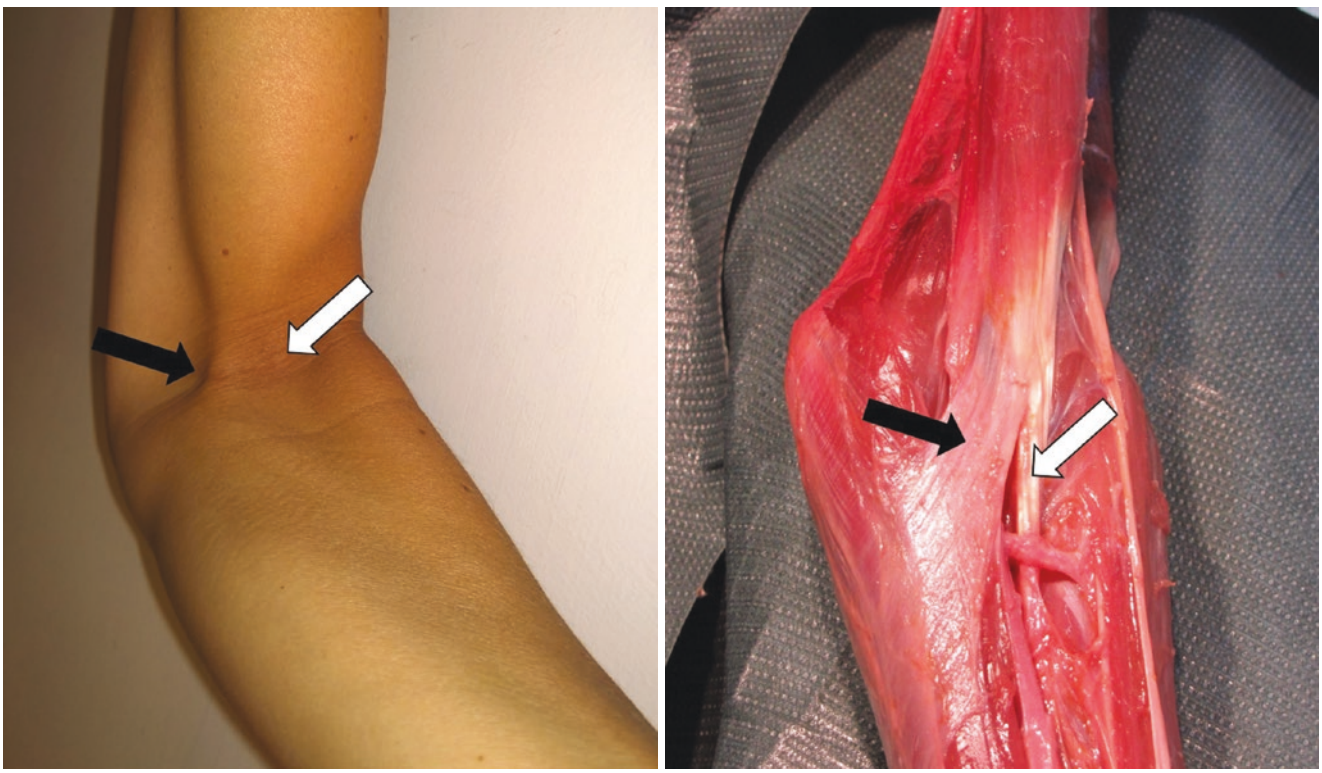


Fig. 4.5 The lacertus fibrosus (*black arrow*) must not be confused with the distal biceps tendon (*white arrow*)

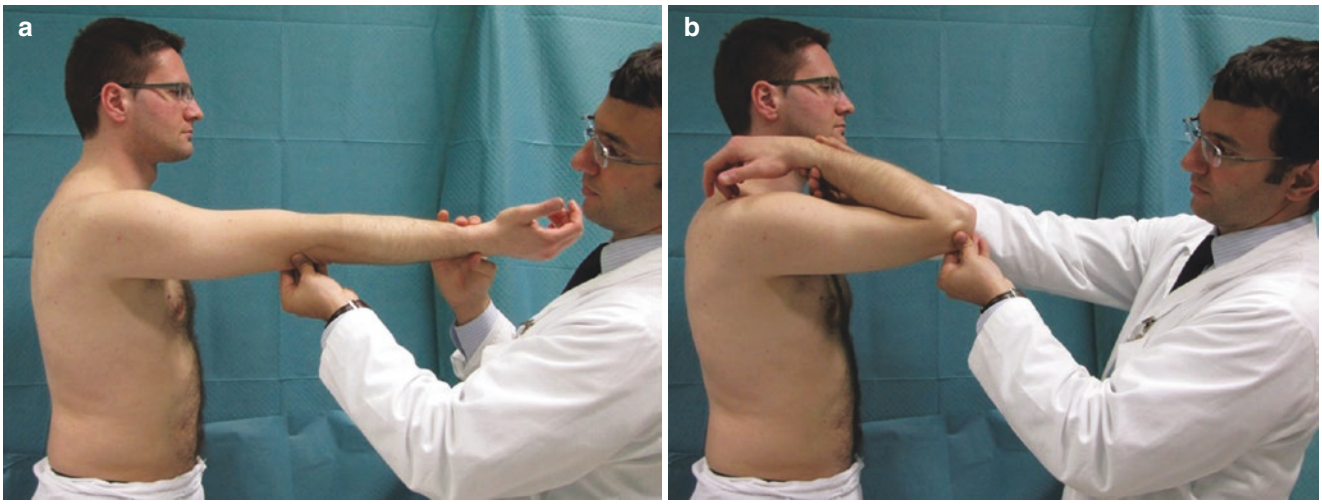


Fig. 4.6 The normal ROM is considered to be between 0° (**a**) and 145–150° (**b**)

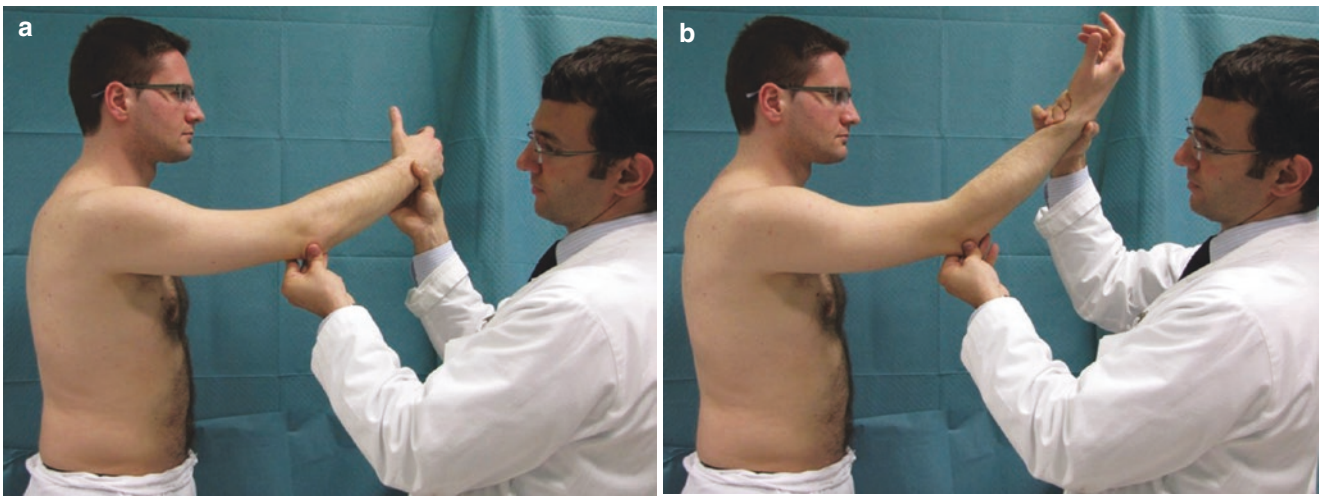


Fig. 4.7 With the arm internally rotated, the physician can measure an angle of 20° (**a**). When the position of the shoulder and of the forearm is correct, the physician can measure an angle of 40° (**b**)

The patient is then instructed to flex the elbow as fully as possible keeping the humerus parallel to the floor and the forearm supinated. The normal ROM ranges from about 0° to 145–150° (Fig. 4.6).

Hyperextension of the elbow (typical of female patients) can suggest a condition of generalized ligamentous laxity. In cases of significant swelling, extension will be limited since the position of maximum joint capacity is around 80° of flexion (Beetham 1965). In cases of flexion or extension contracture, it is important to focus our attention on crepitus during the excursion and on the end points (either solid or soft).

Particular attention should be paid to the position of the shoulder and of the forearm. The figures show an incorrect position of the arm which can lead the observer to an overestimation of the ROM. If the arm is internally rotated, the physician can underestimate the flexion angle (Fig. 4.7).

Pronation and supination are usually measured with the elbows at the side and flexed 90°. Their normal values range around 80° and 90°, respectively (Fig. 4.8).

Thanks to the standardization of the patient's position for ROM evaluation, goniometric measurements taken from photographs have been demonstrated to be an accurate and reliable method for measuring the active ROM of the elbow with important potential implications for evidence-based medicine, comparative effectiveness research and cost containment (Blonna et al. 2012).

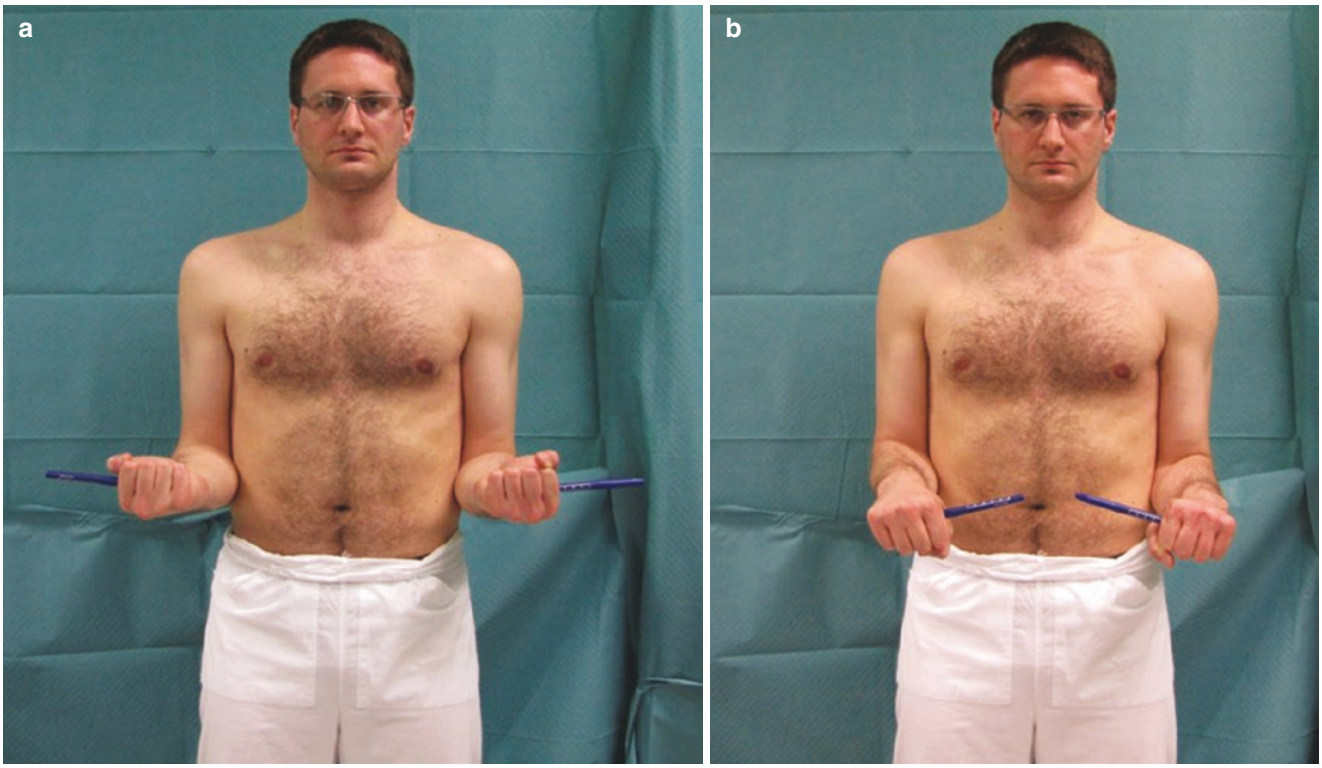


Fig. 4.8 The normal values of supination (**a**) and pronation (**b**) range around 90° and 80°, respectively

Key Points
A functional range of motion is 30° of extension to 130° of flexion.

An incorrect position of the arm can lead the observer to an overestimation of the ROM.

4.4 Clinical Assessment of Specific Elbow Disorders

This section is divided into subchapters based on the areas where patients identify their main symptoms.

4.4.1 Medial Symptoms

4.4.1.1 Medial Epicondylitis

The patient typically experiences medial pain with resisted wrist flexion.

Another pain-inducing manoeuvre can be helpful in the physical examination: the examiner palpates the medial epicondyle with one hand and grasps patient's wrist with his other hand; the patient, while making a fist, pronates the forearm and extends the elbow against resistance (Jobe and Ciccotti 1994).

4.4.1.2 Medial Collateral Ligament (MCL) Pathology

The MLC is the most important soft tissue constraint to valgus instability. It consists of an anterior bundle, a posterior bundle and a transverse bundle (Fig. 4.9). Of the three bundles, the anterior one is the strongest one and the most frequently involved in valgus instability.

Moving Valgus Stress Test

One of the most useful tests for the diagnosis of an MCL lesion is the moving valgus stress test (a dynamic evolvement of the milking manoeuvre which is shown below). With the elbow in full flexion, the examiner replies a constant valgus torque to the elbow and then quickly extends the elbow (Fig. 4.10).

Most commonly, the patient exhibits symptoms (usually pain or apprehension) at around 90° of flexion. The test is positive if it reproduces the medial symptoms of the patient and if these symptoms are maximal between 70° and 120° of flexion (the so-called shear angle). The same symptoms are typically experienced by the patient from extension to flexion at the same shear angle. The test is highly sensitive (100%)

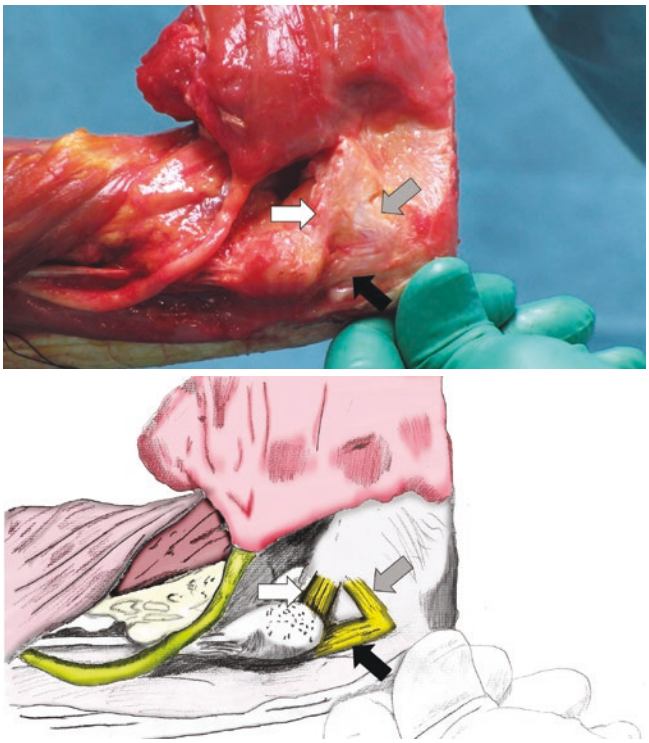


Fig. 4.9 The medial collateral ligament consists of an anterior bundle (*white arrow*), a posterior bundle (*black arrow*) and a transverse bundle or Cooper's ligament (*grey arrow*)



Fig. 4.10 The moving valgus stress test

and specific (75%) for painful partial/complete tears of the MCL in overhead-throwing athletes (O'Driscoll et al. 2005).

Milking Manoeuvre

The examiner stresses the elbow in valgus at approximately 90° of flexion and palpates the MCL. The arm is abducted and the forearm supinated. The test is positive if the manoeuvre reproduces patient's symptoms (usually pain and apprehension) in the medial aspect of the elbow. The manoeuvre tests in particular the posterior band of the anterior bundle of the MCL (Jobe and Kvitne 1991) (Fig. 4.11).

A modified version of the milking manoeuvre has been described with the shoulder in adduction and maximum external rotation (shoulder external rotation can be a confounding variable): one examiner's hand holds the elbow at around 70° of flexion and palpates the medial joint line, while the other hand pulls down on the patient's thumb creating a valgus stress (Hariri and Safran 2010).

Valgus Stress Test

One of the most popular tests for medial instability is the valgus stress test or elbow abduction stress test. However, despite its popularity, this test is the most difficult to perform and interpret with a high rate of false-positive and false-negative results (sensitivity 66% and specificity 60% (Timmerman et al. 1994). It tests in particular the anterior band of the anterior bundle of the MCL. There is no consensus both regarding the position of the hand and the degree of elbow flexion during the test (Morrey et al. 1991; Callaway et al. 1997; Schwab et al. 1980; Sojbjerg et al. 1987; Safran et al. 2005). Based on our experience, the test should be performed at around 30° of flexion with the shoulder at around 90° of abduction and fully externally rotated, since it is easier to control humeral rotation. Pronation can help in avoiding false-positive results due to posterolateral instability (O'Driscoll 1994, 2000); moreover in pronation, the MCL, if not insufficient, protects the elbow against valgus stress (O'Driscoll et al. 1991; Morrey and An 1983, 1985) (Fig. 4.12).

The test is not to be performed in full extension: the congruent articulation of the olecranon in the olecranon fossa stabilizes the elbow against the varus and valgus forces. If the elbow is unstable in full extension, one should suspect bone abnormality, including fracture. Paradoxically, a complete lesion of the anterior and posterior bundle of the MCL associated with a complete avulsion of the flexor-pronator muscle can be not diagnosed with the elbow in full extension.

The test is positive for a grossly unstable elbow, usually associated with fractures: with a complete lesion of the anterior bundle of the MCL, it is only slightly positive. The test is useful with diagnostic arthroscopy, stress radiographs or under fluoroscopy (Fig. 4.13).

Key Point

The valgus stress test should be performed at around 30° of flexion and with the forearm in pronation to avoid false-positive results due to posterolateral instability. Always consider using fluoroscopy.

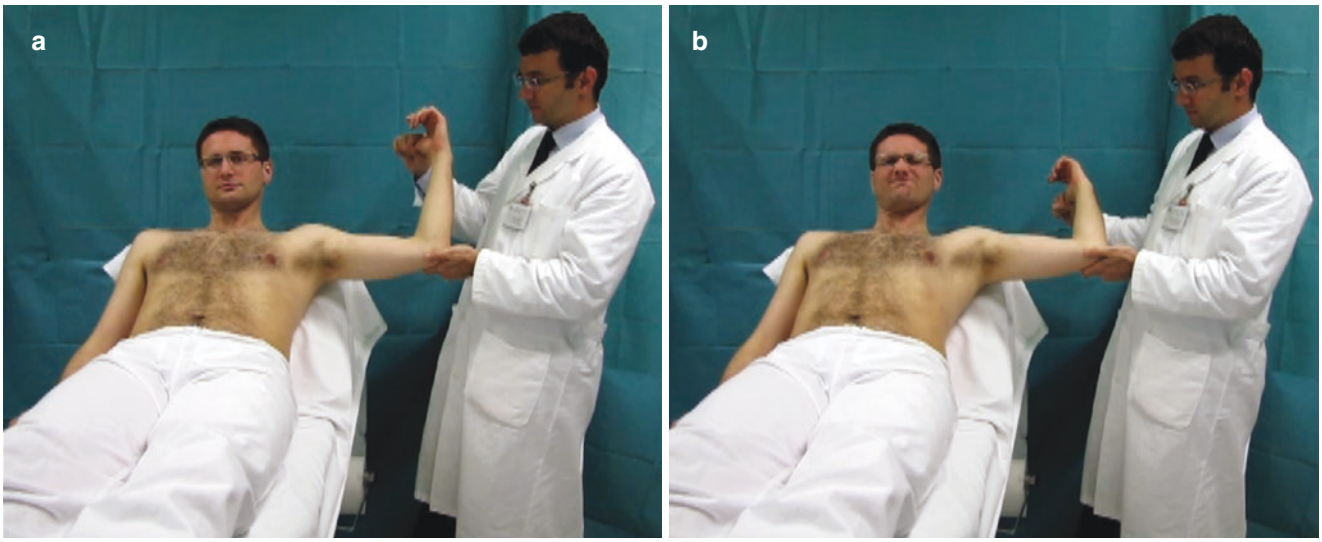


Fig. 4.11 The milking manoeuvre. (**a**) starting position. (**b**) final position

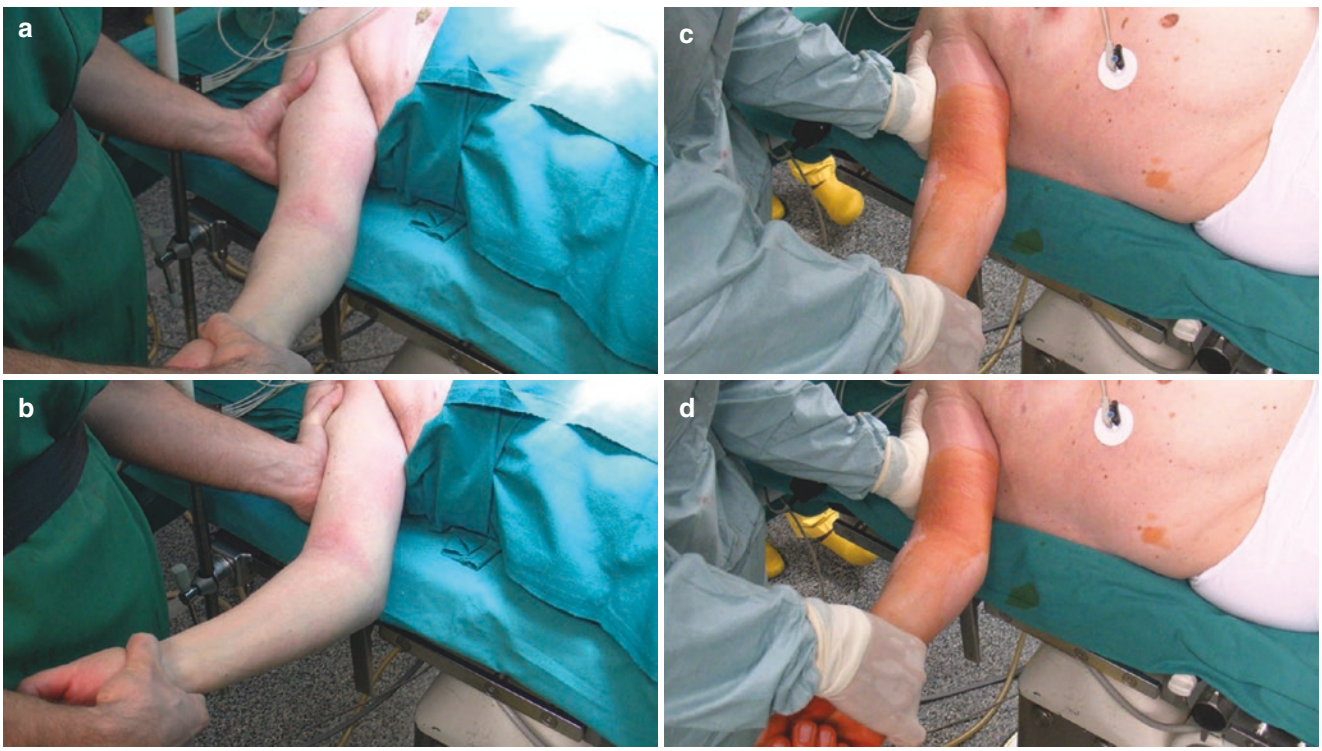


Fig. 4.12 The valgus stress test. Panels A and B show a positive preoperative valgus stress test. Panels C and D show a negative test after radial head replacement

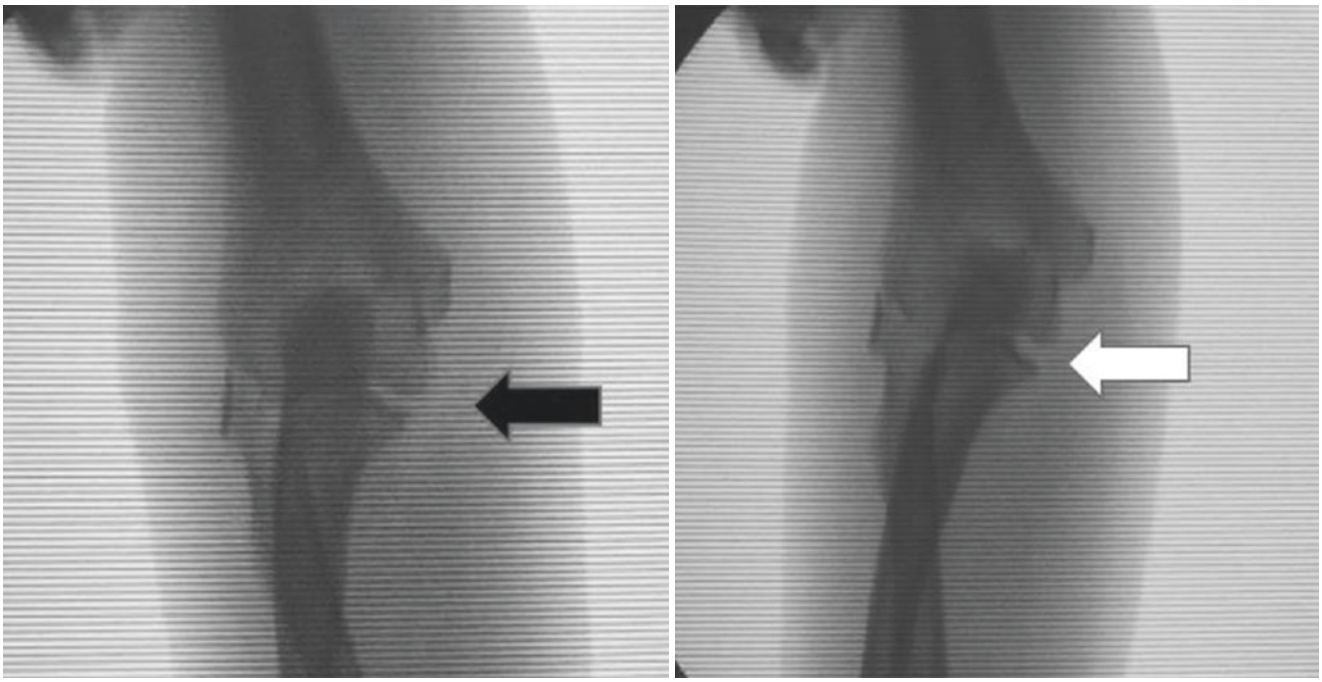


Fig. 4.13 Elbow fluoroscopic evaluation. The *black arrow* indicates the medial side of the elbow. The *white arrow* indicates the opening of the joint during the valgus stress test

4.4.1.3 Cubital Tunnel Syndrome

Apart from the Tinel sign already cited above, other tests can be useful for a proper diagnosis. In a recent literature review, the Tinel sign and the elbow flexion test were the only highly recommended tests. The other tests described below (apart from the last one) are recommended tests (Valdes and LaStayo 2013).

Elbow Flexion Test

The test is performed by maximally flexing the elbow passively for 1–3 min with the shoulder in neutral position, the forearm supinated and the wrist in full extension. The test is considered positive if the patient exhibits paraesthesia or worsening of pre-existing paraesthesia in the ulnar nerve distribution in the small and ring fingers (Buehler and Thayer 1988).

Shoulder Internal Rotation Test

The test is performed with 90° of abduction, maximum internal rotation and 10° of flexion at the shoulder, 90° of flexion at the elbow, forearm and wrist in neutral position and fingers in full extension. The test is considered positive if any slight symptom attributable to ulnar nerve dysfunction occurs within 10 s (Ochi et al. 2011).

The authors have subsequently described a modified version of this test, the shoulder internal rotation elbow flexion test (Ochi et al. 2012): maximum elbow flexion, maximum forearm supination and maximum wrist extension are added to the position of shoulder internal rotation test for 5 s.

Scratch Collapse Test

The patient is asked to face the examiner and resist shoulder external rotation with the elbows flexed at his sides and both hands outstretched with wrists in neutral position. Then the area over the ulnar nerve at the elbow is then scratched, and the manoeuvre is repeated. The test is positive if the examiner can appreciate a temporary loss of shoulder external rotation resistance (Cheng et al. 2008).

Subluxating Medial Triceps and Ulnar Nerve Instability

It is a common condition, but in only few cases does it become symptomatic (usually with the irritation of the ulnar nerve). When the patient flexes his elbow, the examiner can palpably appreciate the ulnar nerve and the medial side trying to dislocate over the epicondyle. In order to improve the sensibility of the test, we suggest performing the test from flexion to extension with the patient extending the elbow against the force of the examiner. Moreover, the ulnar nerve can be observed to displace anteriorly during flexion (Childress 1975) (Fig. 4.14).

Key Point

The Tinel sign and the elbow flexion test are highly recommended tests to diagnose cubital tunnel syndrome. Always test concomitant ulnar nerve instability.

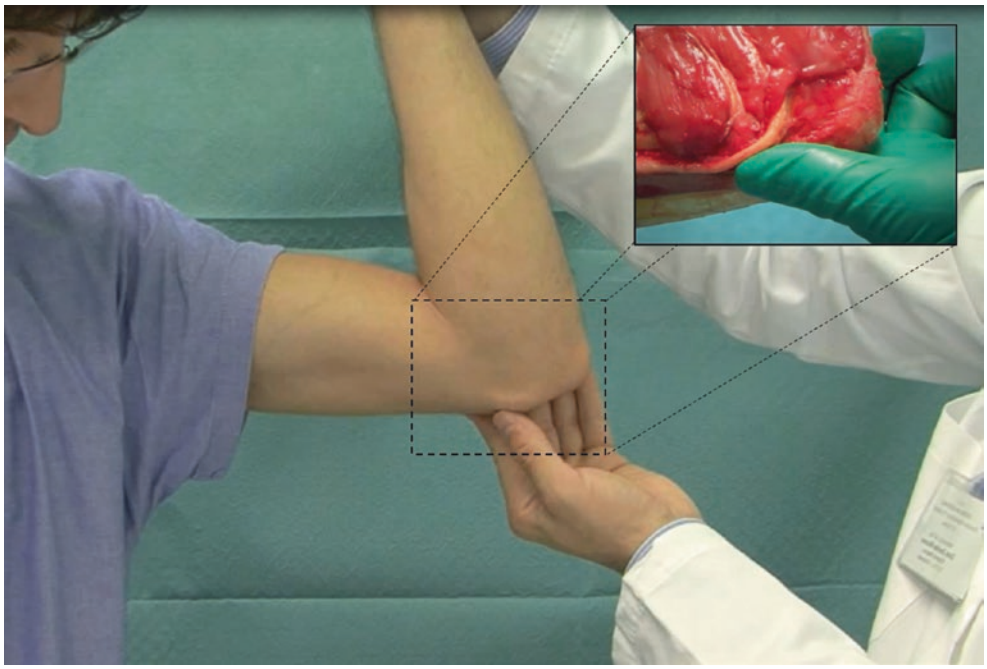


Fig. 4.14 From flexion to extension of the elbow, the examiner can palpate with his finger the ulnar nerve trying to dislocate

4.4.2 Lateral Symptoms

4.4.2.1 Lateral Epicondylitis

Cozen Test

The patient is asked to make a fist and to extend the wrist in a pronated position, while the examiner applies a counterforce against the wrist with one hand and palpates the lateral epicondyle with the other hand (Cozen 1962). Also, the patient typically feels pain and a loss of strength, especially with the elbow in an extended position (Dorf et al. 2007).

Chair Test

This test has been described as the most important clinical finding in cases of tennis elbow. The examiner asks the patient to lift a chair with one hand in a pronated position, and the patient feels significant lateral pain (Gardner 1970).

Maudsley Test

The patient is asked to actively extend the middle finger against resistance. This test specifically evaluates the integrity of the extensor carpi radialis brevis tendon. The authors who described the test believe an entrapment neuropathy of the radial nerve and its branches (often caused by a tightened origin of the extensor carpi radialis brevis tendon) can be involved in the pathogenesis of persistent cases of tennis elbow (Roles and Maudsley 1972).

4.4.2.2 Posterolateral Rotatory Instability

Lateral Pivot Shift Test

The lateral pivot shift test (O'Driscoll et al. 1991) is performed with the patient supine and the affected elbow overhead. It can also be performed with the patient sitting and with the arm on his/her waist, but the former position allows an easy control of humeral rotation, and in cases of a bulky upper limb, the examiner can hold the forearm with both hands. With the forearm supinated, valgus and axial loading is applied, and the elbow is flexed from full extension. With flexion usually beyond 40°, the radial head suddenly reduces with a palpable and visible clunk. However, the positive result often consists only of patient's apprehension if he/she is not under anaesthesia. It is frankly positive usually only in cases of significant instability. It is specific but not sensitive (Fig. 4.15).

Posterolateral Rotatory Drawer Test

The posterolateral rotatory drawer test (O'Driscoll 2000) can be performed with the patient seated and the forearm resting on the patient's waist or with the patient supine, the arm overhead and the elbow flexed 40°. We suggest the second position because it is usually used during general anaesthesia. Anteroposterior force is applied to the radius and the ulna with the forearm in supination. The aim is to subluxate the forearm away from the humerus on the lateral side. Compared to the lateral pivot shift test, it is less specific but more sensitive.

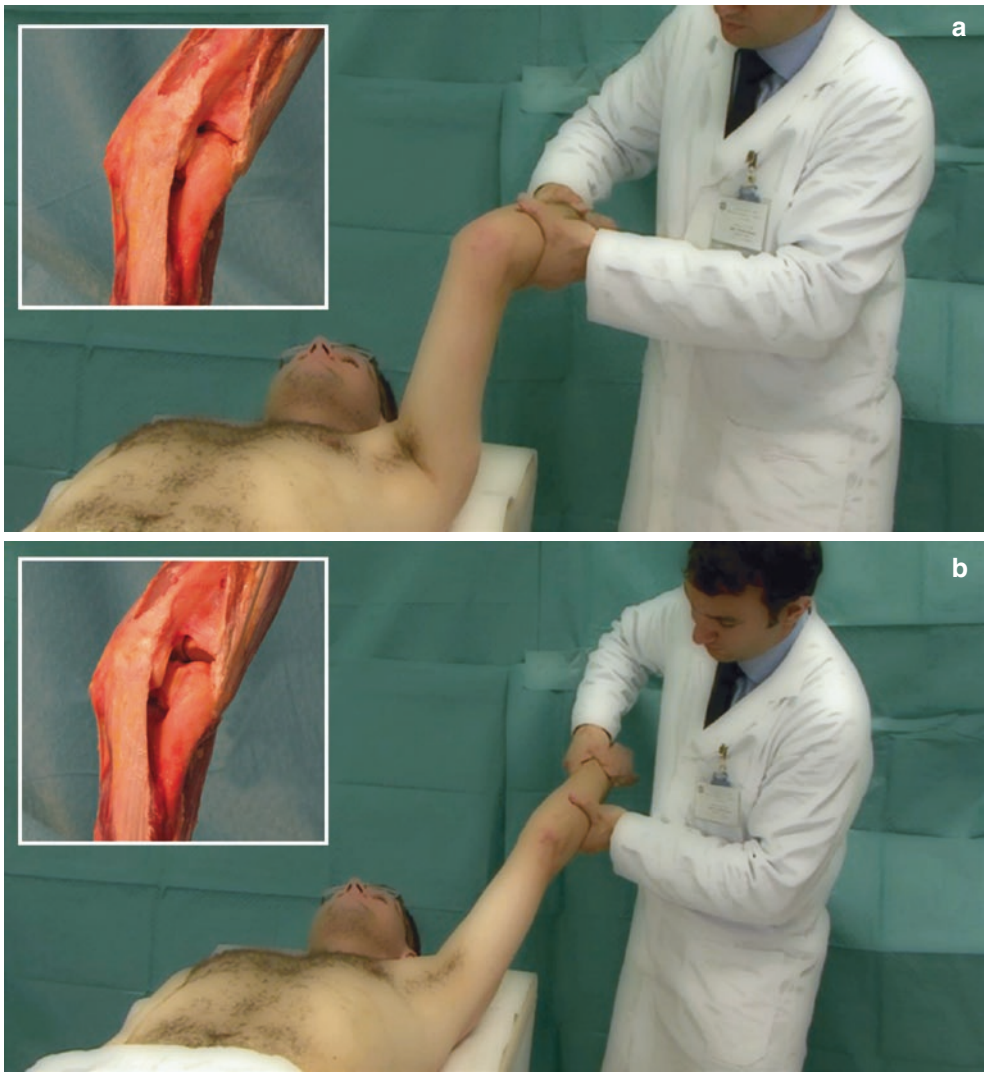


Fig. 4.15 Lateral pivot shift apprehension test. With the elbow flexed usually beyond 40°, (**a**) the radial head reduces. In extension, it subluxates (**b**)

Stand-Up Test

The test is performed actively by the patient him/herself and is also called the "chair sign". The patient is asked to attempt to stand up from the sitting position out of a chair using arms in supinated position. The association of compression, valgus stress and supination makes the patient avoid extension of the elbow because of apprehension or even dislocation. The sensitivity of the test is 87.5% (Regan and Lapner 2006).

Push-Up Test

The patient is prone on the floor with his elbows in full flexion, his forearms in supination and his arms abducted to greater than shoulder width. The test is positive if the patient experiences apprehension or dislocation while attempting a full extension of the elbow. The sensitivity of the test is 87.5%; however, if it is combined with the stand-up test, the sensitivity is 100% (Regan and Lapner 2006).

Table Top Relocation Test

The table top relocation test is a modified version of the push-up test. The patient is asked to perform the same movement of the push-up test but facing the edge of a table. At approximately 40° of flexion, the patient's symptoms are reproduced. Then the examiner places his thumb over the radial head to prevent posterior subluxation, while the test is repeated (in a manner similar to the relocation test for shoulder instability). Finally, the thumb is suddenly removed and symptoms arise again (similar to the surprise test for shoulder instability).

The stand-up, push-up and table relocation tests are highly sensitive but low in specificity since radiocapitellar articular pathology often causes pain. However, the table relocation test may partially help in reducing false-positive results thanks to its second and third manoeuvre (Arvind and Hargreaves 2006).

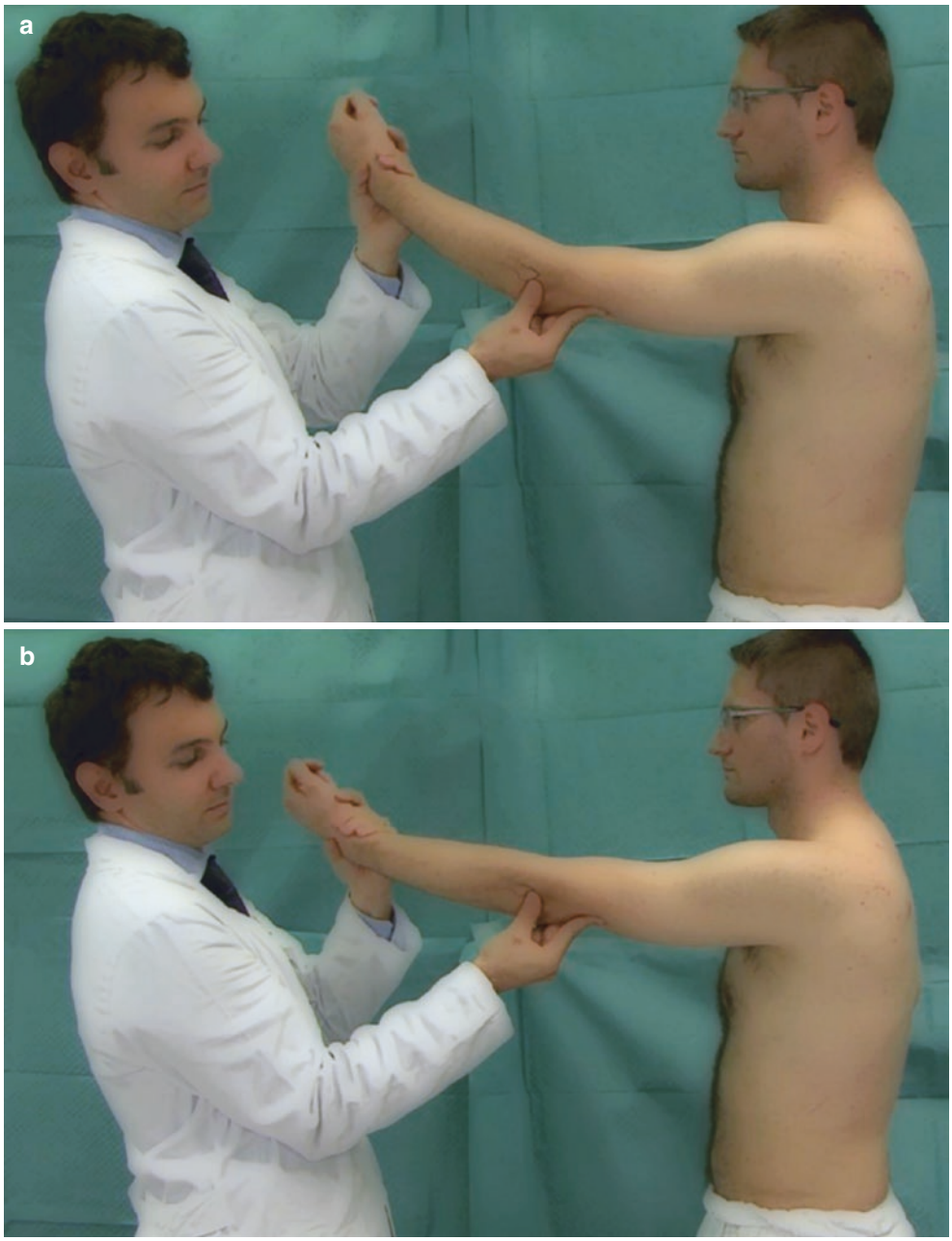


Fig. 4.16 Extension supination test. The examiner palpates the posterolateral soft spot from flexion (**a**) to extension (**b**)

Key Point
The lateral pivot shift test is best performed with the patient supine and the affected elbow overhead.

4.4.2.3 Anterolateral and Posterolateral Plica

The anterolateral and posterolateral plicae of the elbow are described to be frequently misdiagnosed during physical examination of the elbow.

Flexion-Pronation Test

This test evaluates the anterolateral plica. The examiner reproduces the patient's painful snapping in the anterolateral side of the elbow between 90° and 120° degrees of flexion with the forearm in pronation (Antuna and O'Driscoll 2001).

Extension Supination Test

For the posterolateral plica, the extension supination test has been shown to reproduce patients' symptoms. The examiner reproduces the patient's painful snapping in the posterolateral side of the elbow (or soft spot) in full extension and forearm supination (Ruch et al. 2006) (Fig. 4.16).

4.4.3 Anterior Symptoms

4.4.3.1 Distal Biceps Tendon Pathology

One of the diseases that commonly causes anterior elbow pain is a rupture of the distal biceps tendon. A misdiagnosis of the distal biceps tendon rupture is not a rare event. A substantial delay of the diagnosis can preclude the ability to perform a primary reinsertion.

It has been recently shown that a combination of the hook test with the passive forearm pronation test and the biceps crease interval test (described below) results in 100% sensitivity and specificity (Devereaux and ElMaraghy 2013).

Hook Test

To perform the hook test, the patient is asked to actively flex the elbow to 90° while sitting or standing with the fully supinated forearm. The examiner's index finger is brought from the anterolateral side of the cubital fossa beneath the lateral side of the distal biceps tendon in an attempt to hook it. In a normal patient, the finger can be inserted beneath the tendon to approximately 1 cm. It is important the patient does not flex the elbow against resistance but actively supinate his forearm as much as possible.

The test has been shown to have a sensitivity and specificity of 100% (higher than with MRI). However, if the test is performed incorrectly, the examiner can miss some cases. One of the most common mistakes is the wrong position of the forearm: doing the test with the forearm in neutral position or even in pronation causes false-positive results. With a complete avulsion of the distal biceps tendon, the hook test is abnormal as indicated by the absence of a cordlike structure behind which to hook the examiner's finger.

The test is also useful to distinguish between avulsion and partial tear, with the latter being associated with a painful hook test (O'Driscoll et al. 2007) (Fig. 4.17).

Lag Sign

The lag sign is a test designed to assess the supination effect of the biceps muscle. The examiner holds the patient's forearm in full passive supination and asks the patient to hold this position. Then the examiner suddenly releases the forearm and records the degree of pronation that occurs. With an intact distal biceps tendon, the lag is virtually absent because the distal biceps tendon keeps the forearm in full supination. In case of biceps avulsion, the examiner observes a few degrees of lag (Hertel, 2007, personal communication).

Squeeze Test

The squeeze test is performed with the patient seated and the forearm resting on his/her lap or on a table. The elbow is flexed at approximately 60–80°. The forearm is slightly pronated. The biceps muscle is squeezed, and the examiner observes a small supination of the forearm. Attention should be paid to where to squeeze the biceps muscle: the tendency is to squeeze the biceps in the middle of the arm. However, this often gives a false-positive result. The arm must be



Fig. 4.17 The hook test

squeezed in the most distal part of the humerus. In case of distal biceps tendon rupture, the forearm does not supinate. A sensitivity of 96% has been reported (Ruland et al. 2005).

Passive Forearm Pronation Test

The test is performed with the elbow in 90° of flexion relaxed on the patient's side. One examiner's hand is on the patient's hand to control pronation and supination, while the other hand palpates the biceps muscle during passive motion. The examiner looks for a consistent and dose-dependent response to the passive pronation of the forearm (Harding 2005).

Biceps Crease Interval Test

The test relies on the proximal migration of the biceps and on surface anatomy of the arm. Two anatomical landmarks have to be taken into consideration and marked on the skin: the antecubital crease and the distal aspect of the biceps muscle belly. A distance between these landmarks greater than 6 cm or a ratio between the non-injured and the injured arm greater than 1.2 cm suggests a tendon rupture (sensitivity 96%, specificity 93%) (ElMaraghy et al. 2008).

Bicipital Aponeurosis Flex Test

The patient is asked to make a fist, supinate his forearm and flex the wrist. Then, maintaining this position, he is asked to flex his elbow at around 75°. An intact bicipital aponeurosis can be felt medially in the antecubital fossa (ElMaraghy and Devereaux 2013).

Key Point

The hook test must be performed with the forearm actively supinated. A wrong position easily causes false-positive results.

4.4.4 Posterior Symptoms

4.4.4.1 Posterior Impingement

Two different types of posterior impingement have been described: posteromedial and posterolateral. However, the symptoms exhibited by patients are remarkably similar.

Posteromedial impingement is related to repetitive valgus and extension overload during overhead activities. This is an easy test to reproduce the posterior pain during terminal extension.

4.4.4.2 Triceps Tendon Rupture

Triceps tendon rupture is rare but must be taken into consideration. The diagnosis is typically made clinically, but tears are often misdiagnosed. Apart from tenderness, swelling, ecchymosis, muscle spasms or tendon defect (which can be not easy to appreciate), the squeeze test has been described (Viegas 1990). It is a modified version of the Thompson test for the Achilles tendon rupture: the patient is asked to place his elbow flexed over the end of the table in a prone position (in this position, the extension of the elbow against gravity is more reliable, and it is also easier to detect weakness in extension against resistance); the triceps is squeezed, and the examiner will appreciate some extension of the elbow in cases of an intact tendon.

4.5 Scores

Accurate tools for assessing preoperative physical examination and clinical results are mandatory in the era of evidence-based medicine. Both self-reported scales and objective assessment instruments have been developed and serve as useful tools to evaluate clinical results. However, it is important to distinguish between scoring systems designed to be administered by patients or by the physician especially in cases of comparison between our clinical results and the results shown in the literature.

Although many rating scales have been described, not every score has been validated or has undergone a high-quality validation process. In a recent systematic review that included 12 different elbow-specific scoring systems, the Oxford Elbow Score was found to be the only tool validated using high-quality methodology (The B et al. 2013). In this chapter, we will illustrate only the most common scores.

4.5.1 Physician-Administered Scores

4.5.1.1 Mayo Elbow Performance Index (MEPI)

The MEPI is a tool used worldwide which takes into consideration four parameters:

- Pain: from 0 (severe) to 45 points (none)
- Motion: from 5 (arc <50°) to 20 points (arc >100°)
- Stability: from 0 (gross instability) to 10 points (stable)
- Function: five points for each of the following ADL—combing hair, feeding, hygiene, donning shirt and donning shoes

The total score ranges from 5 to 100 points: if the total score is higher than 90, it is considered excellent; from 75 to 89, it is considered good; from 60 to 74, it is fair; and if lower than 60, it is considered poor. The MEPI was designed particularly for assessing ADL, so it should be used with caution for the evaluation of athletes (Morrey 1993). It has been recently proven to have high reliability when used to assess nonsurgical treatment (Cusick et al. 2014). Several variants of the MEPI have been described (Verstreken et al. 1998; Broberg and Morrey 1987; Regan and Morrey 1989).

4.5.1.2 American Shoulder and Elbow Surgeons-Elbow (ASES-E)

The score has been developed by the Research Committee of the ASES. It consists of both a patient self-evaluation section and a section to be completed by the physician.

The first part is divided into three sections: pain (visual analogical scale), function (patients are asked whether they can perform ten activities of daily living and to rate their ability to perform them) and satisfaction (from 0 to 10).

The second part consists of four sections: motion (assessed with a standard goniometer), stability (valgus, varus and posterolateral rotatory instability are rated from 0 to 3, where 3 stands for gross instability), strength (graded from 0 to 5 according to the Medical Research Council grading system) and clinical findings (a series of possible physical findings are listed, e.g. ulnohumeral tenderness, radiocapitellar crepitus, atrophy and so on) (King et al. 1999).

Liverpool Elbow Score (LES)

The LES consists of a clinical assessment score component and of a patient-rated questionnaire. In the first section, the examiners consider six items regarding ROM, strength and the ulnar nerve; each one is graded either using a four-point scale (from 0 = worst to 3 = best) or a three-point scale (from 0 to 2). In the second section, the patient is asked to answer nine questions about their elbow function and pain; the questions are graded from 0 to 4. All responses are transformed to a scale of 0–10 and equally weighted for summation by averaging: the final LES ranges between 10 (best) and 0 (worst) (Sathyamoorthy et al. 2004). In the AO handbook Musculoskeletal Outcomes Measures and Instruments, the LES is considered a high-quality outcome instrument since it is characterized by a strength score of 9 out of 10 (Suk 2005). The LES has been proven to be a useful tool to assess the outcomes of total elbow arthroplasty in particular (Vishwanathan et al. 2013). Even the patient-answered section alone is considered to be a useful mail-in questionnaire for the assessment of these outcomes (Ashmore et al. 2007).

4.5.2 Patient-Administered Scores

4.5.2.1 Oxford Elbow Score (OES)

The OES is a 12-item questionnaire (with five response options each) devised for assessing outcomes of elbow surgery. Patients have to fill in the questionnaire recalling a period of the last 4 weeks. Each item response is scored as 0 to 4, with 0 representing greater severity. Items are divided into three components: the first one is the "pain domain" and evaluates elbow pain; the second one is the "elbow function domain" and measures the functional impairment referred by the patient because of his/her elbow problem; and the third one is "social-psychological domain" and evaluates both limitations to work, leisure and everyday activities and psychological aspects of the elbow impairment. The OES is not unidimensional, and the examiner cannot simply sum all 12 of the questions: scores for each domain are calculated as the sum of each individual item score and expressed on a scale of 0 to 100 (Dawson et al. 2008).

To date, the OES has been validated in three different languages (de Haan et al. 2011; Plaschke et al. 2013; Ebrahimzadeh et al. 2014). It has been recently compared to other 11 different elbow-specific scoring systems and was found to be the only one that has been formally validated using statistical methodology (The B et al. 2013).

Patient-Rated Elbow Evaluation (PREE)

The score was partially inspired by the previous patient-rated wrist evaluation. In the first section, the patient is asked to rate the average amount of pain in their elbow over the past week from 0 (no pain) to 10 (worst pain) in four different situations and then is asked to answer the question "how often do you have pain?" from 0 (never) to 10 (always). The second section investigates function with a scale ranging from 0 (no difficulty) to 10 (unable to do). Specific activities are investigated through 11 questions (e.g. use a telephone), whereas usual activities through four questions (e.g. recreational activities) (MacDermid 2001).

Subjective Patient Outcome for Return to Sports (SPORTS) Score

The SPORTS score was developed to evaluate athletes' ability to return to sport (Blonna et al. 2010). It was first used to assess the ability of an athlete to return to sport after restoration of elbow extension in athletes affected by elbow contracture. More recently, it has also been validated to score an athlete's ability to return to sport after anterior cruciate ligament reconstruction (Blonna et al. 2011) and after surgical treatment for shoulder instability (Blonna et al. 2014). It is built around three separate concepts:

- The ability to perform the same sport with the same level of effort and training
- The ability to reach the same level of performance
- The ability to do these in the absence or in spite of pain

It is scored on a 10-point scale with 0 points allocated if the patient does not return the same sport and 10 points allocated if the patient performs, without pain, the same sport at same level of effort and performance as before the onset of impairment.

Summary Outcome Determination (SOD) Score

The SOD score is a simple tool with a categorical and a numerical component (Fig. 4.18) to compare surgical outcomes to both the preoperative status as well as to the prein-

Subjective Outcome Determination (S.O.D.)

Categorical Component

How would you rate your elbow now compared to before your surgery? (Choose ***One Category***)

Category	Definition (As Pertaining to Condition Treated)
Normal	As if never diseased, injured or operated*.
Almost Normal	Not normal, but symptoms are of no concern to patient.
Greatly Improved	Quality of life greatly improved, but minor pain and/or impairment present.
Improved	Quality of life improved, but major pain and/or impairment present.
No Better	Quality of life no better or minimally improved; treatment not worthwhile.
Worse	Quality of life worse than before treatment.
Profoundly Worse	Quality of life profoundly worse due to complication of treatment.
As Bad As Dying	Quality of life so severely reduced due to complication of treatment that the patient no longer wishes to live.
Death	Patient has died due a complication resulting from the treatment

*Except for surgical scars.

Numerical Component

On the following scale please circle the ***number*** representing outcome of the elbow after the surgical procedure. A 0 represents no change in your elbow and 10 represents a totally normal elbow, consistent with never having a problem or operation. -10 represents the patient having died as a result of the operation or from complications resulting from the operation.

10	As if never injured or operated*.
9	Almost but not quite normal. However, symptoms have no impact on quality of life or performance.
8	Quality of life and/or performance greatly improved but some residual pain and/or impairment is minor.
7	
6	
5	Quality of life and/or performance improved but major residual pain and/or impairment.
4	
3	
2	Quality of life and/or performance no better or so minimally improved as to make surgery, inconvenience, cost etc., not worthwhile
1	
0	
-1	Worse than before surgery
-2	
-3	
-4	Profoundly worse than before surgery
-5	
-6	
-7	Quality of life so severely reduced due to complication of treatment that the patient no longer wishes to live.
-8	
-9	
-10	Patient has died due a complication resulting from the treatment

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Fig. 4.18 Subjective Outcome Determination (SOD) score. (By permission of Mayo Foundation for Medical Education and Research. All rights reserved)

jury state (Blonna et al. 2010; Finkbone and O'Driscoll 2015). Patients are asked to compare how they feel currently to how they felt before their surgery and to state if they overall consider themselves to be better or worse or they are not sure. If they feel better, they are asked to indicate if they consider the operated part of the body to be improved, greatly improved, almost normal or normal. If they feel worse, the respondent is asked if they are worse, profoundly worse or as bad as dying.

4.5.3 Non-elbow-Specific Scores

4.5.3.1 Disability of Arm, Shoulder and Hand Questionnaire (DASH)

This score consists of three sections (the second and third of which are optional): disability/symptoms, sport/music and work. The first section includes 30 questions about the whole upper limb which are scored from 1 (no difficulty) to 5 (unable). The score of each section is then transformed to obtain the DASH score from 0 (no disability) to 100 (significant disability) (Hudak et al. 1996).

The DASH has been validated and published in several languages; however, the large number of question is an important limitation (at least 27 of the 30 items of the Disability/Symptom section must be completed for a score to be calculated (Institute for Work and Health 2010)). A shorter version of this score, the QuickDASH, has been published (Beaton et al. 2005). It consists of 11 questions, and, similar to the DASH, each one can be scored from 1 to 5, and the final score ranges between 0 and 100.

4.5.3.2 Degree of Shoulder Involvement in Sports (DOSIS) Scale

The aim of the DOSIS scale (Blonna et al. 2015) is to help the physician to classify patients on the basis of their sport activity based on the specific involvement of the shoulder in that sport. As a result of this stratified patient classification, the comparison of clinical results can be more reliable. The DOSIS scale is not intended to indicate whether or not the

patient is ready to return to their sport. The scale is based on three parameters:

- The type of sport: sports are classified as minimal/moderate/high demand on the basis of stress contact and ROM and whether or not they are overhead sports.
- The frequency the sport was played: occasionally/≥2 times per week.
- The level at which the sport was played.

Patients then obtain a score from 0 (no sport) to 10 (high-demand sport played by national/international level or professional athlete).

Even though this scale is weighted for the shoulder, we believe it can be a useful tool in elbow function assessment.

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Approach to the Radiological Imaging of the Elbow

5

Alberto Aliprandi and Alessandro Poloni

The elbow is a complex joint made by the union of three separate joints (a simple hinge joint, a ball-and-socket joint, and a pivot joint). These joints are connected by a single, large capsule and several ligaments. The biomechanical features of these structures allow for complex movements of flexion-extension and pronation-supination (Capo et al. 2014; Wegmann et al. 2014; Sonin et al. 1996). For these reasons, the elbow represents a challenge in terms of diagnosis, therapy, and rehabilitation. Thus, there is a specific clinical need of high-level imaging, aimed to stage correctly the lesions that can be encountered. The technological advancements and the figure of dedicated musculoskeletal radiologists helped to address some critical issues. The transition from analogic to digital radiology, the advent of the multidetector computed tomography (MDCT), and the use of intra-articular contrast media (CT arthrography and magnetic resonance [MR] arthrography) have certainly help increasing diagnostic capabilities both acutely and chronically. The high resolution of MDCT images and the *new capabilities of post-processing* as the reconstruction in various planes of the space (*multiplanar reconstruction* [*MPR*]) and the generation of three-dimensional images have significantly helped to improve the diagnosis in the acute elbow trauma (O'Driscoll 2000; Tarassoli et al. 2013; Sormaala et al. 2014). Of note, more recent CT scans, despite the large number of images generated by these systems, allowed for a significant reduction of the radiation exposure, which is particularly important in younger patients and in those who need repeated examinations. *MRI* has always been considered the pivotal imaging modality in musculoskeletal disease. It is probably the modality that most has taken advantage of technological developments, including new three-dimensional imaging sequences, innovative softwares, and improvement of receiving coils, which led to an increased diagnostic performance in most fields of musculoskeletal pathology. Furthermore, the extreme rapidity of MR sequences allows for performing imaging also in patients with painful joints, taking advantage of posttraumatic joint effusion to achieve an arthrographic-like effect.

Ultrasound (*US*) has always been criticized for being operator dependent, but it has indisputable advantages related to its immediacy, dynamism, and immediate comparison with the contralateral side. The technological development makes US a surprising and valuable tool in some cases, in which it is able to subvert the usual diagnostic flowchart. Routinely US is considered the second instance imaging method, usually used after plain radiography examination. However, it should be regarded also a potential important complement to MRI (Chai et al. 2015; Ciccotti et al. 2014; Park et al. 2014).

In radiology, the study on the elbow is certainly lagging far behind other joints. A quick PubMed search with the terms "elbow MR," "hip MR," "knee MR," and "shoulder MR" showed that elbow is taken in consideration in as much as 5% of scientific papers (Pubmed—March 2015). Thus, there is the need of further, high-quality research to improve diagnostic capabilities of this very complex joint.

Regarding diagnostic imaging, the elbow should be considered differently compared to other joints. The scheme of a rigid diagnostic flowchart should be abandoned in favor of a patient-based approach, tailored on the specific need and timing of the involved joint. In this setting, it should be kept in mind that diagnostic skills of musculoskeletal radiologists and diagnostic equipments may suffer from remarkable variations in different area of the world. Thus, the diagnostic approach should take into account these differences. However, if the diagnostic flowchart for high-energy trauma is fairly standardized, including plain radiography (Morrey 2002; Grayson 2005) and CT (Sormaala et al. 2014), the real challenge is represented by medium-energy trauma, in which joint damage is less obvious. On the other hand, timing of imaging evaluation in respect to trauma seems to play a cru-

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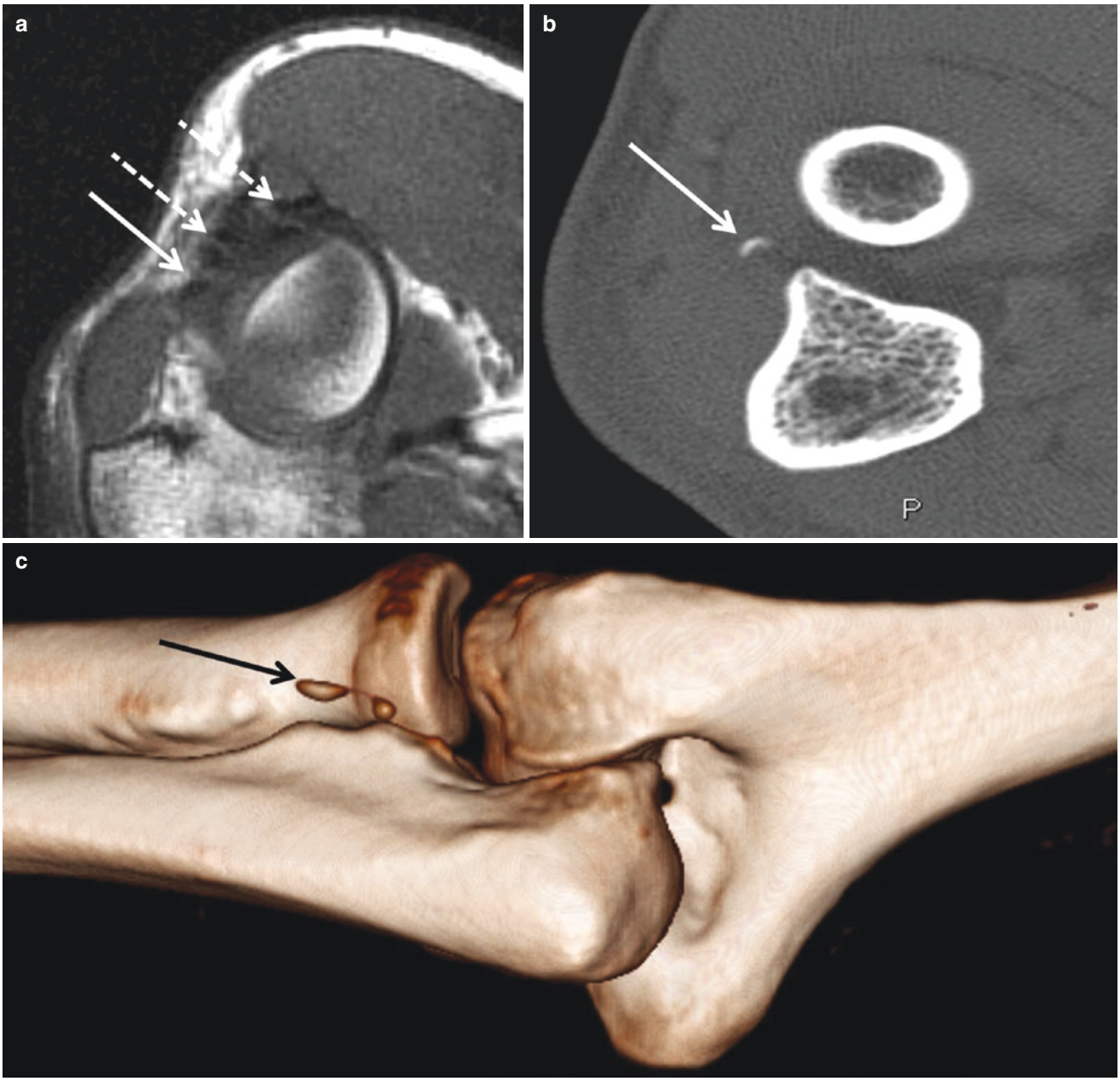


Fig. 5.1 A very small bone fragment of the posterior annular ligament insertion is an indirect sign of a posterior radial head subluxation. The fragment is well identified in CT (**b**) or 3D CT reconstruction (**c**) (*arrow*), while in MRI (**a**), it is more difficult to distinguish the hypointense signal of the tendon (*dotted arrows*) from the bone fragment (*arrow*)

cial role, as the variation of the sensitivity of the various imaging modalities seems to be not negligible. Thus, we may hypothesize a different diagnostic work-up based on timing after trauma:

Acute phase (*within 24 h*): At this time, plain radiography and occasionally CT are needed to correctly assess the fracture/dislocation damage. A paper by O'Driscoll et al. underlined how the fracture of the sublime tubercle represents an important indirect sign of ulnar collateral ligament avulsion. Similarly, other bone detachments may be the sign of ligament strain, as in the case of the annular ligament. These detachments are often minimal and can be well documented with CT but are barely visible on plain radiography and MRI (Fig. 5.1).

Early subacute phase (*24–96 h*): Patients evaluated at this time generally have suffered an average-energy trauma and

Table 5.1 Flowchart of different imaging modalities in relation to trauma timing

Elbow trauma	X-ray	US	CT	MRI	CTa	MRa	US post[a]
Acute	+		+	+			
Early subacute	+		+	+			
Late subacute	+	+			+	+	+
Chronic	+	+	+			+	+

[a]US post = US performed after other examinations for dynamic assessment in varus and valgus stress

come from nonspecialized centers, have been clinically underestimated, or come spontaneously after some hours from trauma due to increasing pain. Obtaining a complete anamnesis is extremely important in these patients, as often the dynamics of the trauma are unclear. Bone damage is usually subtle at this stage and should be investigated in depth. The use of MRI at this stage is still controversial, as damage may be overestimated. However, there is a clear advantage given by the natural arthrographic effect of the posttraumatic effusion that may help obtaining valuable information about capsular insertions, ligaments, tendons, and muscles. Also, bone bruise pattern may help obtaining important information to understand the dynamics of trauma.

Late subacute phase (*4–20 days*): Patients seen at this time have usually undergone a period of posttraumatic immobilization for conservative treatment or are patients with considerable delayed presentation for having underestimate the accident. The elapsed time and immobility can reverse both effusion and edema of the periarticular soft tissues. This does not allow for taking advantage of the natural arthrographic effect given by joint effusion. If at this stage, the question of the clinician is aimed at the reconstruction of the dynamics of trauma and at the study of bone and ligament damage, CT or MR arthrography may be extremely helpful (Cotten et al. 1997). In these cases, US allows for demonstrating dynamic instability. Performing test in varus/valgus stress, actively executed by the operator, allows for measuring the distance between the bones at rest and after stress. In these cases, US can be a useful complement to CT or MRI (Ciccotti et al. 2014).

Chronic phase (*after 20 days*): The diagnostic flowchart should set considering the prevalent clinical need, i.e., instability, joint stiffness, periarticular calcifications, or osteophytes at later stages. CT should be used first to evaluate a stiff elbow (Zubler et al. 2010). On the other hand, MRI is more suitable to research chondral damage or synovial diseases. MR arthrography can be effectively used to assess serious instability (Schaeffeler et al. 2013).

Thus, we can figure a scenario in which the use of each imaging modality is related to the timing of the trauma, as shown in Table 5.1.

Another great chapter in the pathology of the elbow is represented by professional or sportive overuse, in which the sport or professional gesture are crucial in the choice of the diagnostic approach. In tendon disorders, the role of plain radiography and CT appears obviously marginal (useful only in advanced chondral pathology and in research of minutes overload osteophytes), while US, in expert hands, represents the cheapest option that can demonstrate tendon abnormalities. However, MRI and MR arthrography remain the most comprehensive method for the investigation of tendon, ligamentous, chondral, and capsular damage (see Chap. 7) (Schaeffeler et al. 2013).

5.1 Plain Radiography Examination of the Elbow

As mentioned, plain radiography is the first diagnostic step and must be conducted according to international standards. The proper execution of a radiogram is a prerequisite both for diagnostic purposes and for the choice of any further investigation. The aim of this chapter is to explain how to interpret the most used radiographic views for the study of the elbow, to know their limitations, and to understand if they are properly made. Unfortunately, in trauma patients, it is not always easy to meet the correctness criteria due to pain and joint stiffness. However, some devices are available to try keeping the joint in the correct position.

The two fundamental views for evaluating the elbow are the anteroposterior and the lateral views, obtained with projections 90° one from the other. There are also oblique projections, targeted to study medial and lateral joint bone structures. To better understand the image that we are looking at, it is essential to understand how this was obtained. In the *anteroposterior view*, the patient is generally positioned sitting near the table, with the hand supinated and the arm fully extended, resting on the radiographic cartridge. The radiation source is placed in front of the joint itself, usually on the top, and is centered on the elbow (Fig. 5.2a). In this way, joint space between the humerus and radius-ulna will be well displayed, as well as medial and lateral humeral epicondyles (Fig. 5.2b). To better assess the olecranon and ulnar coronoid, the study must be completed with a *lateral projection*, obtained by flexing the arm 90° with the hand in supination, leaning the ulnar side against the radiological cartridge and keeping the thumb upward (Fig. 5.3a). A properly performed lateral view should show three concentric circles at the distal humerus level, representing,

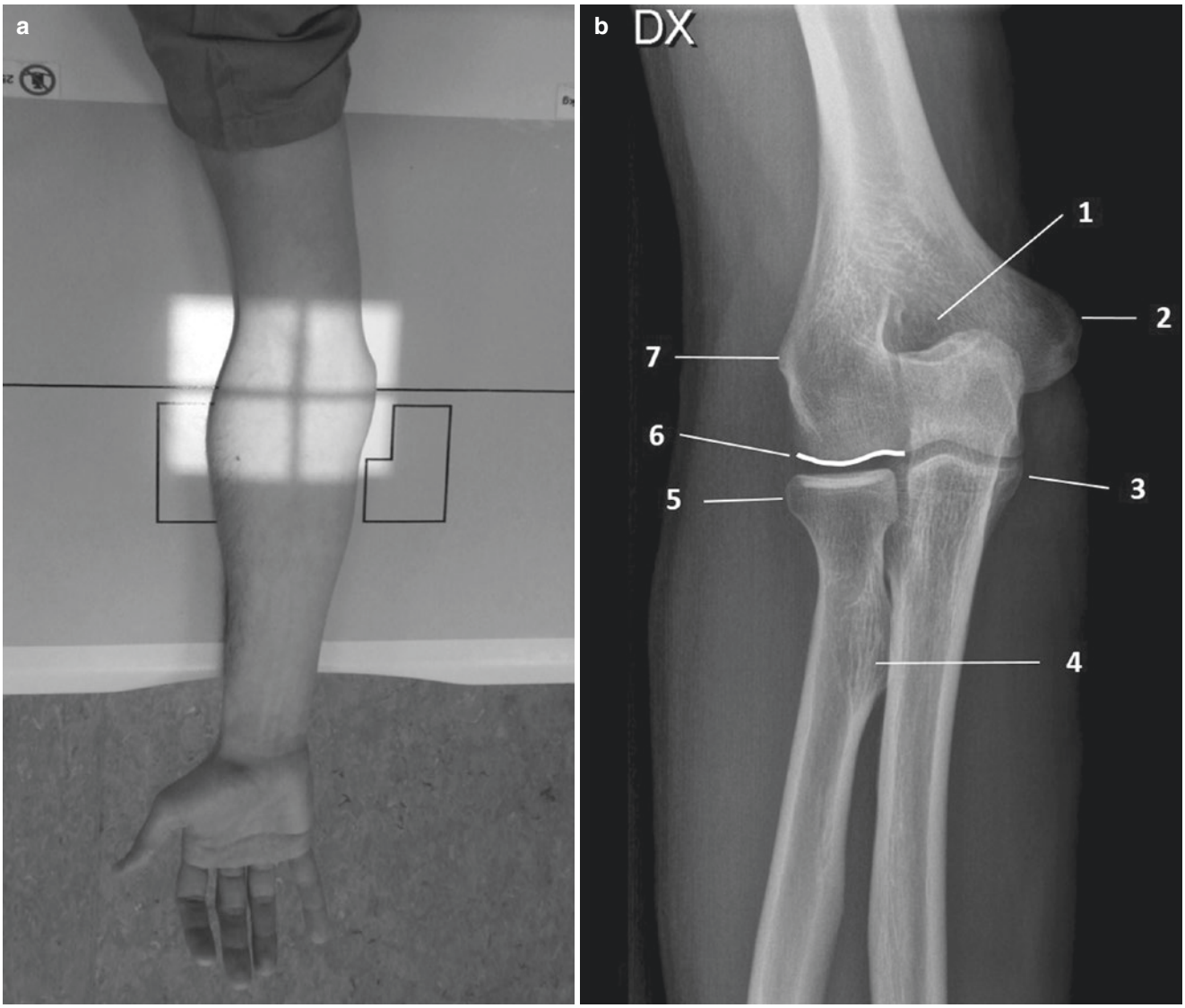


Fig. 5.2 Normal anteroposterior view of the elbow–(**a**) patient positioning with fully extended arm (**b**) (1) olecranon fossa, (2) medial epicondyle, (3) coronoid process, (4) radial tuberosity, (5) radial head, (6) humeral radial articular surface without bony overlap, (7) lateral epicondyle

respectively, (from smallest to largest) the trochlear groove, the capitulum humeri, and the trochlea (Fig. 5.3b). In painful elbows, however, the circles may not be perfectly allineated due to positioning difficulties. In addition, other complementary projections may be performed to investigate selectively other skeletal structures. The *oblique medial view* provides good visualization of the humeral trochlea and proximal ulnar structures (olecranon and coronoid). The position of the patient is similar to that of the anteroposterior view but with the patient's arm rotated inward and with pronated hand (Fig. 5.4a). This position allows for assessing the ulnar coronoid without bone overlapping (Fig. 5.4b) but is not optimal for evaluating the radial head, which overlaps the proximal end of the ulna and is therefore poorly visible. Maintaining this position, but rotating the patient's arm to the outside and with the hand on its back, *oblique side view* can be performed. It is very important that the forearm and hand are in external rotation (Fig. 5.5a), as this position allows for imaging the lateral structures of the elbow at best, namely, the capitulum humeri and the radial head (Fig. 5.5b). However, the radial head can be

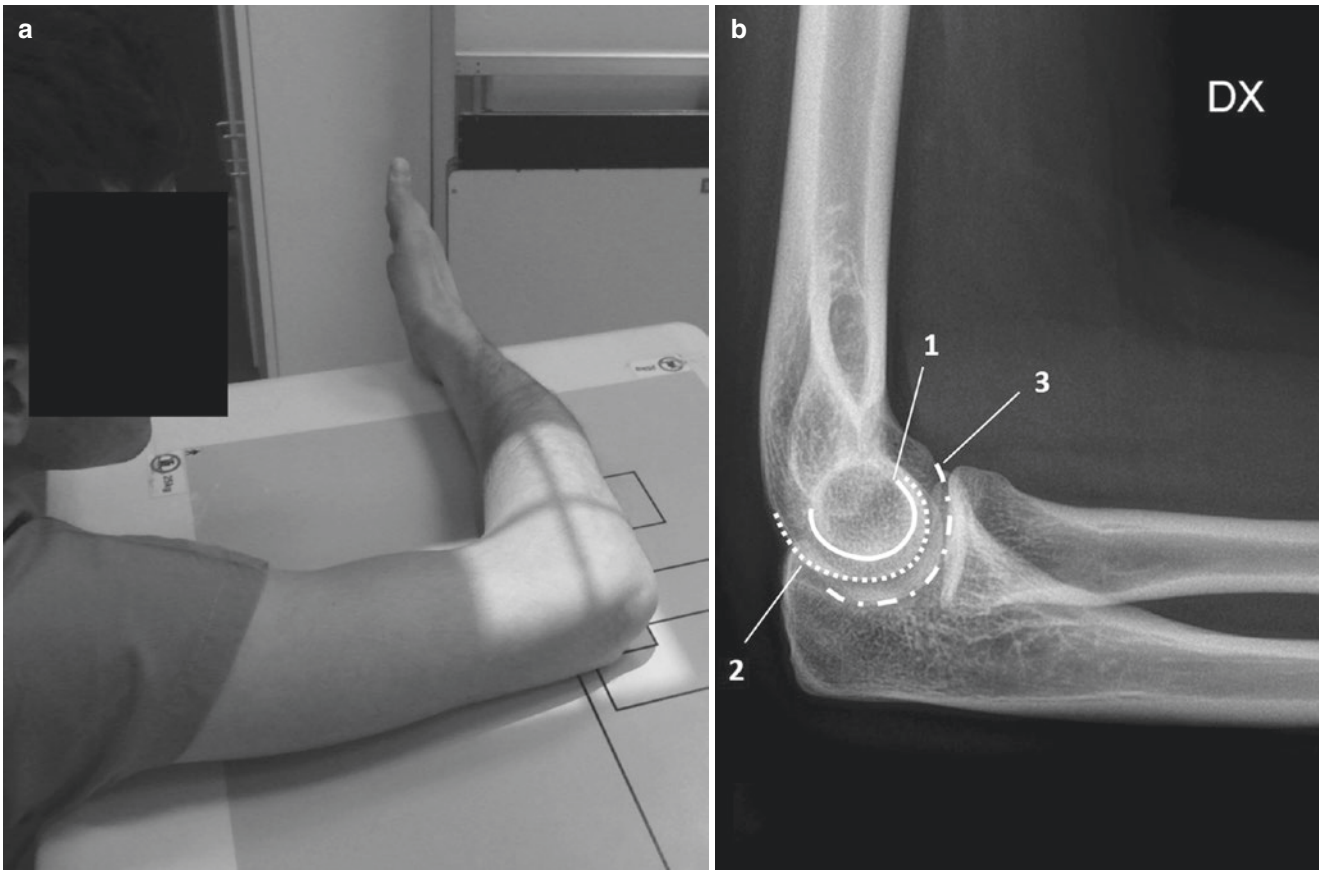


Fig. 5.3 Normal lateral view of the elbow—(**a**) patient positioning with the elbow held in 90° flexion (**b**) visualization of the three concentric *circles*: (1) trochlear sulcus, (2) capitulum humeri, (3) trochlea

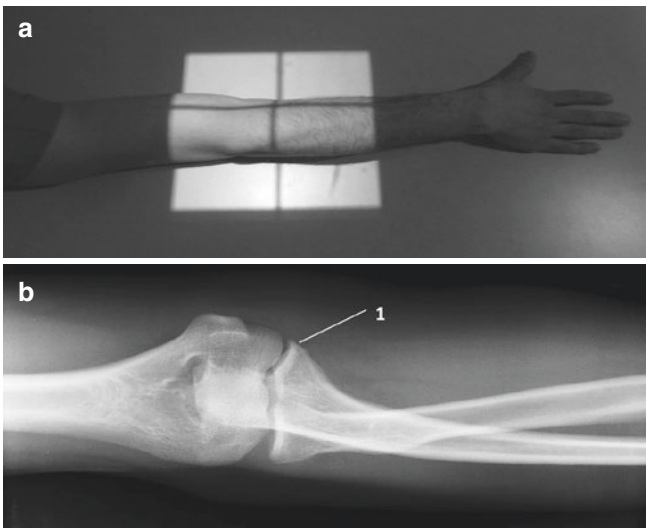


Fig. 5.4 Medial oblique view of the elbow—(**a**) patient positioning with extended arm and pronated hand (**b**) complete visualization without bony overlap above the coronoid process (1)

investigated more selectively by a *specific projection for the radial head* (also called *oblique radial*), very useful in trauma, made with the patient placed with semi-flexed elbow, leaning on the radiological cartridge. The radial head should then be imaged isolated (Fig. 5.6b) with the X-ray tube oriented about 45° in caudal-cranial direction (Fig. 5.6a). As an alternative to this position, the incident beam can be kept perpendicular to the elbow (direct from the front to back), but the patient is imaged with elbow extended, with the ulnar side in hyper supination. Although difficult to obtain in an acute setting, the study of the elbow can be completed with an *axial view*, useful in case of suspected fractures of the olecranon or of the condyles and the ulnar groove. The patient is positioned lateral to the radiographic table, on which the forearm and hand with semi-flexed elbow rest (about 110°). The radiation beam is perpendicular to the olecranon that must be positioned at the center (Fig. 5.7a). This projection provides the best visualization for the isolated olecranon,

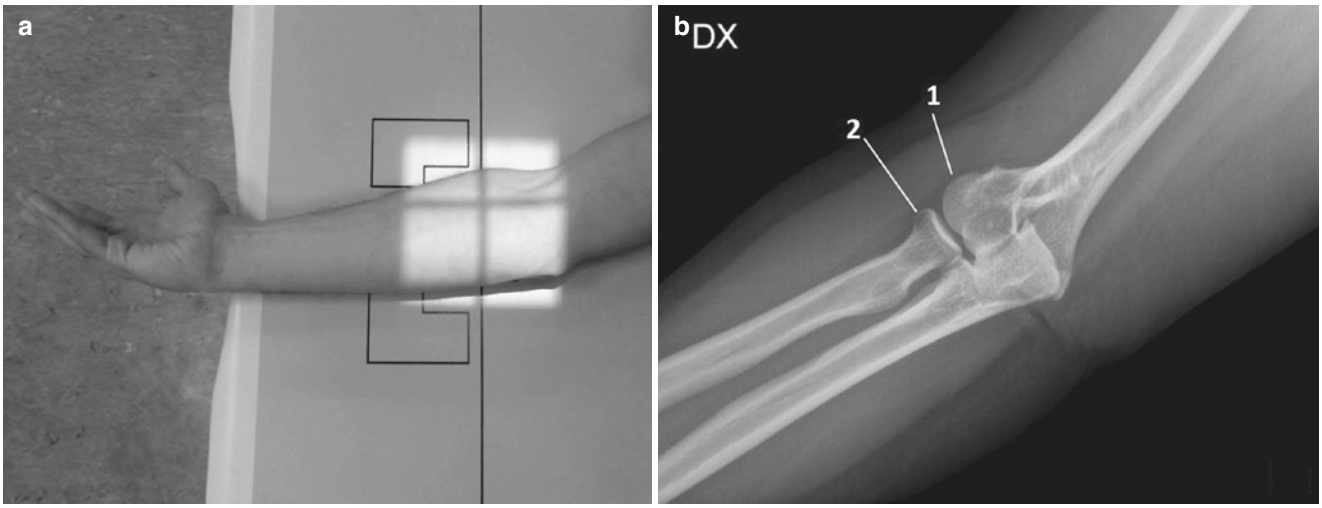


Fig. 5.5 Lateral oblique view—(**a**) patient positioning with extended arm and supinated hand (**b**) complete visualization without bony overlap of the capitulum humeri (1) and radial head (2)

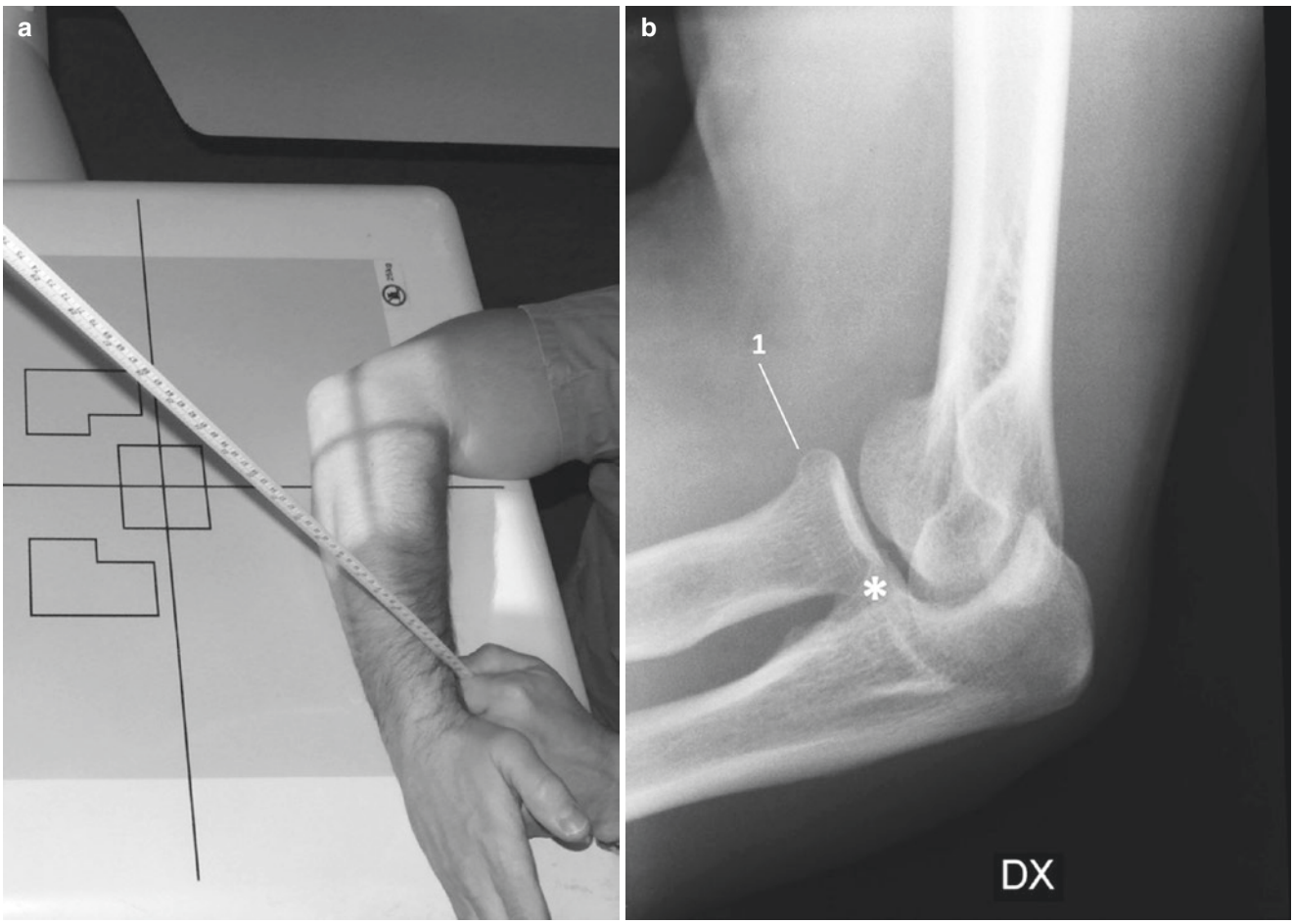


Fig. 5.6 Radial oblique view to assess the radial head—(**a**) patient positioning. (**b**) Complete visualization without bony overlap of the radial head (1). In this case the view is suboptimal due to partial bony overlapping (*)

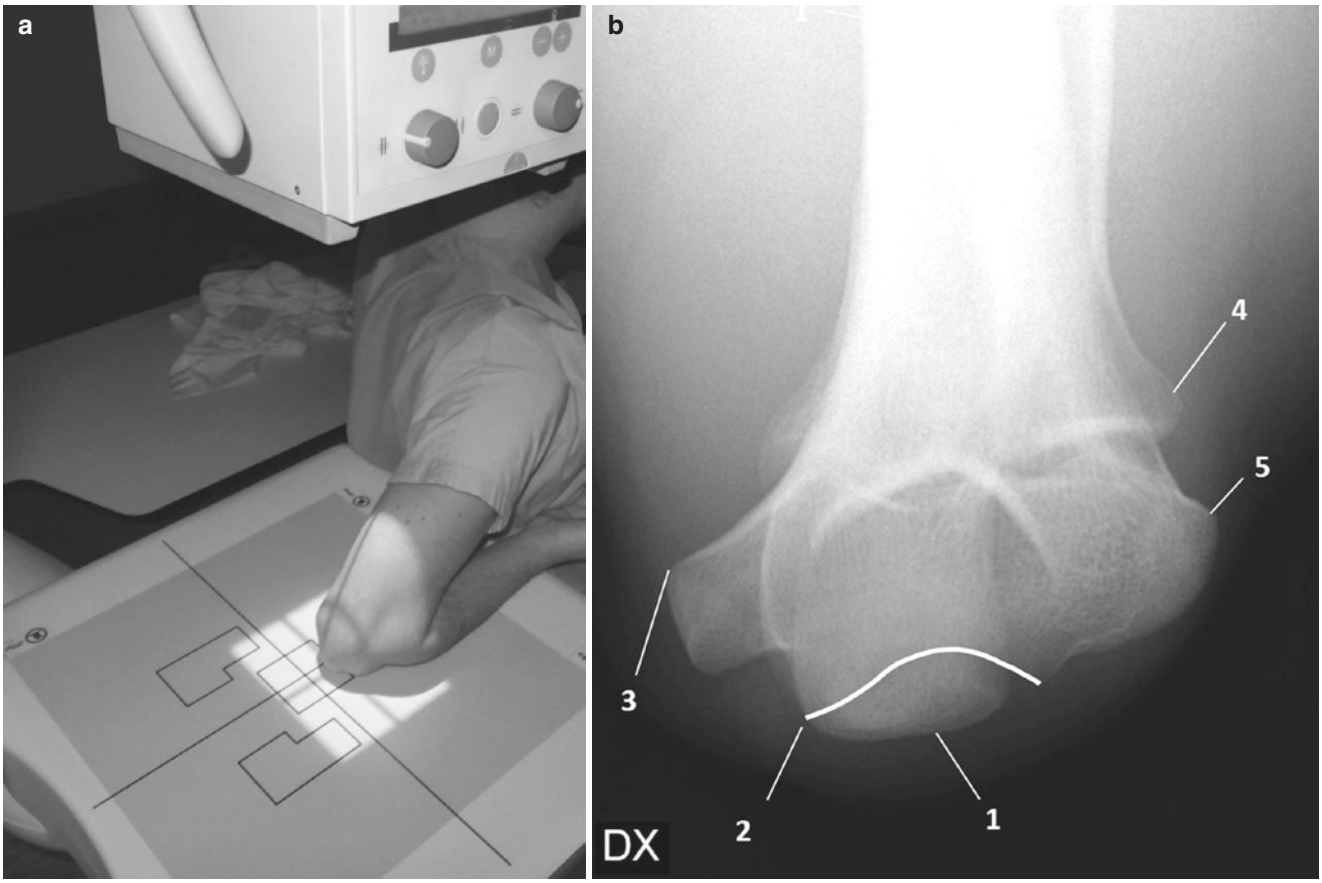


Fig. 5.7 Axial view—(**a**) patient positioning (**b**) isolated visualization of the olecranon (1), humerus-ulnar articular surface (2), medial epicondyle (3), radial head (4), lateral epicondyle (5)

humerus-ulnar joint space, and epicondyles (Fig. 5.7b) (Morrey 2002; Grayson 2005; Mazzucato 1976).

5.2 Main Signs of Trauma on Plain Radiography of the Elbow

Once correctness criteria are respected, plain radiographs should be examined to search for direct and indirect signs of fractures. The main findings are:

1. *Fat pad sign*: Fat pads are joint adnexa that are normally present within the joint capsule of the elbow but outside the synovia. In the lateral view, they are normally hidden behind the olecranon and the coronoid, strictly adhering to the humeral cortex. When joint effusion is present, displaces anteriorly or posteriorly the fat pads, thus showing radiolucent triangular shadows. The presence of a fat pad sign may indicate the presence of a hidden fracture.
2. *Anterior humeral line*: On the lateral view, when drawing a line on the anterior surface of the humerus, at least one third of the capitulum humeri should lie anteriorly. Failure of that may imply the presence of a supracondylar fracture with posterior displacement of the capitulum. However, note that this sign may be not valid especially in children, as a complete ossification of the capitulum is still pending.
3. *Radio-capitellar line*: In lateral projection, the line that divides the radial shaft should intersect the center of the capitulum humeri. Failure of that, dislocation of the radial head should be suspected.
4. *The relationship between capitulum humeri and radial head is constant* and does not change in the different projections. Any changes represent an indirect sign of pathology.
5. *The use of oblique projections is not always able to grade the trauma of the coronoid*. CT is very helpful to obtain an exact classification. (Classification of O'Driscoll or AO).

In conclusion, the radiographic projections made in case of injuries of the elbow require a systematic approach. The lateral view is essential for the assessment of possible joint effusion and the correct alignment of anatomical lines. When needed, the comparison with the contralateral limb may help

in doubtful cases, especially in children when distinction of normal anatomic variations, growth nuclei, or fracture still represents a challenge. Communication between the professionals involved to assess the type of trauma is of paramount importance, to choose the most appropriate diagnostic procedure, and consequently to improve the subsequent therapeutic performance.

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The Role of Ultrasonographic Evaluation in the Elbow Pathology

6

Giuseppe Monetti

6.1 Elbow Ultrasound Imaging

Elbow ultrasound (US) employs static and dynamic scans and 7.5–20 MHz high-frequency transducers (Fig. 6.1).

Color and power Doppler techniques provide excellent imaging of the vascular network (Fig. 6.2), whereas elastography is especially useful for the functional assessment of tissue elasticity, particularly of tendons and muscles (Fig. 6.3).

6.1.1 Degenerative and Post-traumatic Tendon Pathology

The tendon compartment most frequently affected by degenerative and/or post-traumatic conditions is the common extensor tendon at the level of the epicondyle. Its involvement is easily demonstrated by dynamic US (Fig. 6.4).

Inhomogeneous tendon thickening is a common finding at this site; it is related to degenerative and/or traumatic changes and is often associated with calcific tendinopathy at the proximal insertion close to the periosteum (Fig. 6.5).

Patients with more severe conditions often also have bursitis, either acute, with distension due to fluid accumulation, or, more often, organized evolving to fibrosis (Fig. 6.6).

Grade 2 and 3 traumatic lesions of the common extensor tendon frequently involve the radial collateral ligament proper, which is closely anatomically connected to the tendon (Fig. 6.7).

At this level, severe injury often results in formation of fibrotic and scar tissue involving both tendon and ligament, giving rise to meniscoid syndrome. The syndrome often causes joint clicks in maximum elbow extension and arthrosynovitis that tends to become chronic (Fig. 6.8).

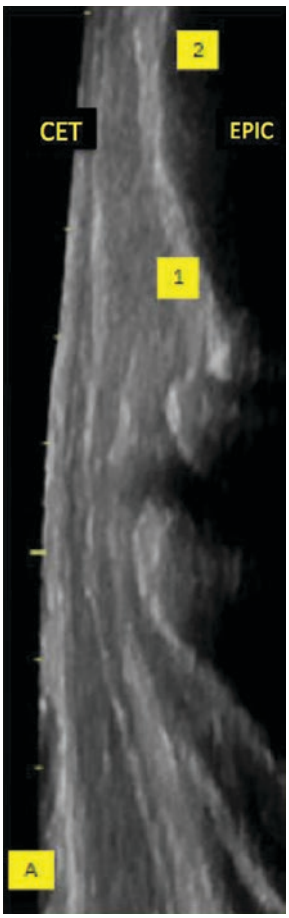


Fig. 6.1 Sagittal scan (15 MHz probe): insertion of the common extensor tendon (CET) into the epicondyle

The common extensor tendon and the common flexor tendon—which inserts into the medial epicondyle—share a very similar symptomatology (Fig. 6.9).

The ulnar collateral ligament is less severely involved, especially its anterior and medial bundles, due to the loose anatomical association of the tendon and ligament.

Patients with epicondylitis or epitrocleitis (golfer's elbow) benefit from dynamic US scanning at the level of both the

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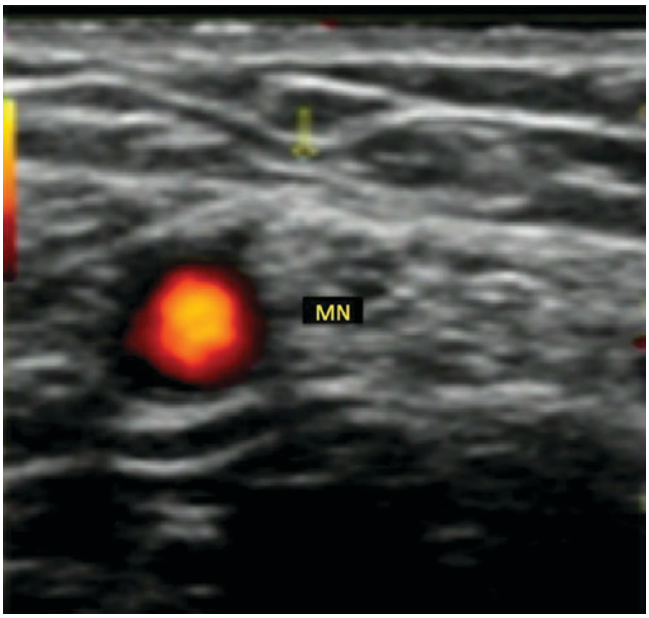


Fig. 6.2 Axial section (15 MHz probe) at the level of the ventral area: brachial artery with the median nerve (MN) running parallel to it

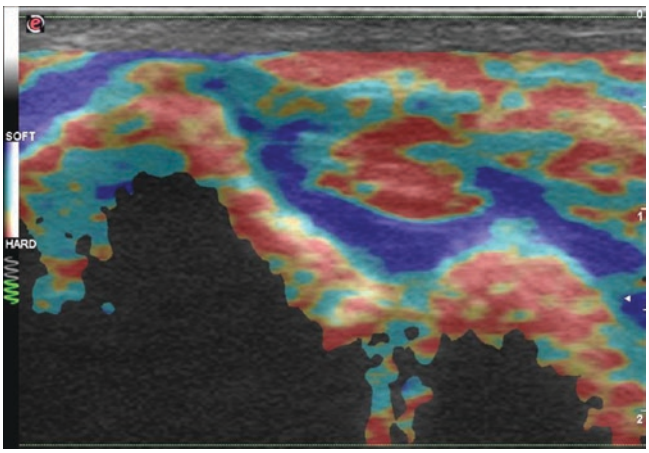


Fig. 6.3 Sagittal section at the level of the common extensor tendon insertion: dynamic scan in contraction (elastography) documenting reduced tendon elasticity

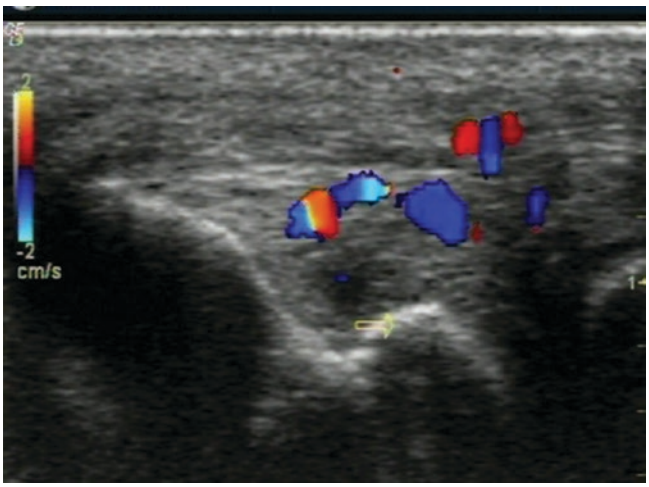


Fig. 6.4 Degenerative tendinopathy of the proximal insertion of the common extensor tendon and distressed areas also depicted by color Doppler

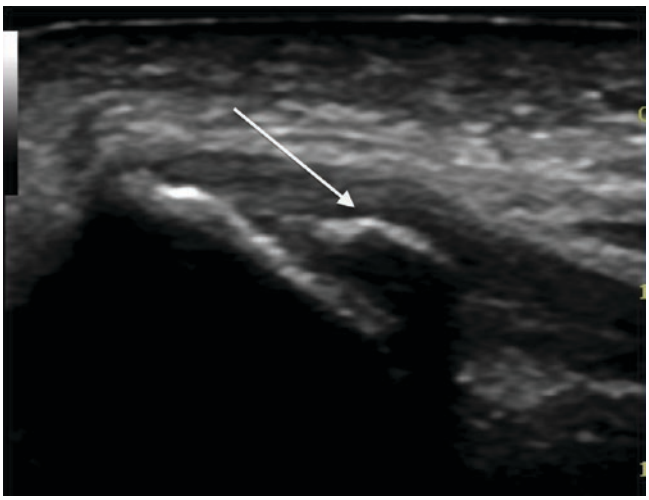


Fig. 6.5 Calcific tendinopathy of the proximal insertion of the common extensor tendon

extensor and the flexor muscles, where significant muscle edema is often documented in relation to antalgic contraction due to enthesitis of the proximal tendon insertion (Fig. 6.10).

Another anatomical structure frequently involved by enthesitis is the triceps tendon. Its olecranon insertion has a distinctive anatomical configuration, with the true tendon in the center and the medial head of the triceps muscle in close contact with the course of the ulnar nerve.

Post-traumatic or hypertrophic muscle changes often result in direct nerve compression (Fig. 6.11).

The main degenerative condition affecting the olecranon area is bursitis, either acute, with swelling due to fluid buildup, or more often organized, showing fibrosis and calcifications (Fig. 6.12).

Abscess formation at the level of the bursa is a not uncommon complication (Fig. 6.13).

The distal insertion of the biceps muscle tendon into the radial tuberosity deserves a separate discussion, since 60–65% of the world population shows a double insertion, i.e., proximal (long head of the biceps tendon) and distal (short head) (Fig. 6.14a, b).

The fact has considerable implications, especially for clinical and functional evaluation, because the two tendons would serve different functions, the former in maximum flexion and the latter in pronation-supination. The two tendons are

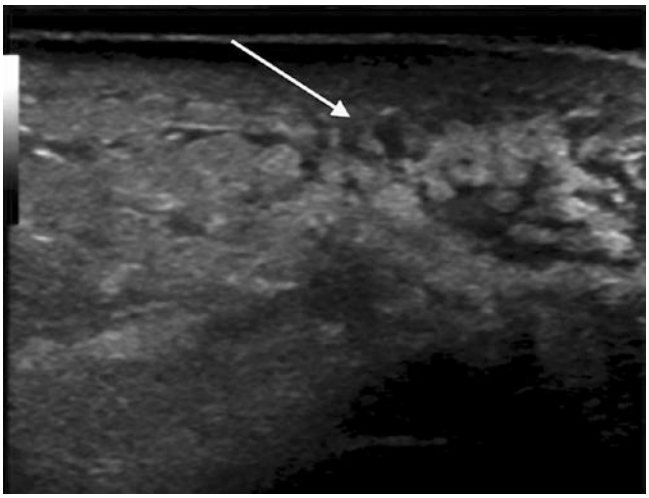


Fig. 6.6 Periolecranic bursitis undergoing organization

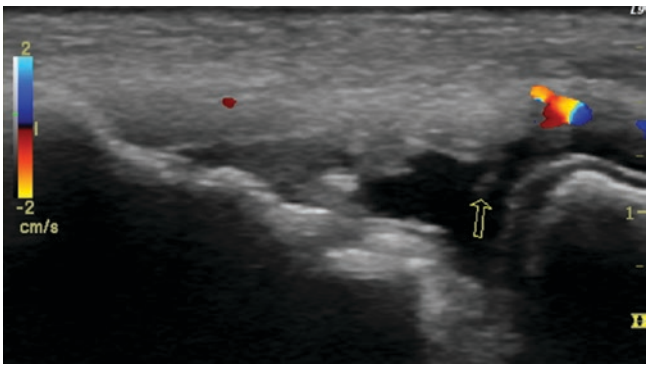


Fig. 6.7 High-grade lesion of the common extensor tendon with involvement of the ulnar collateral ligament (*arrow*)

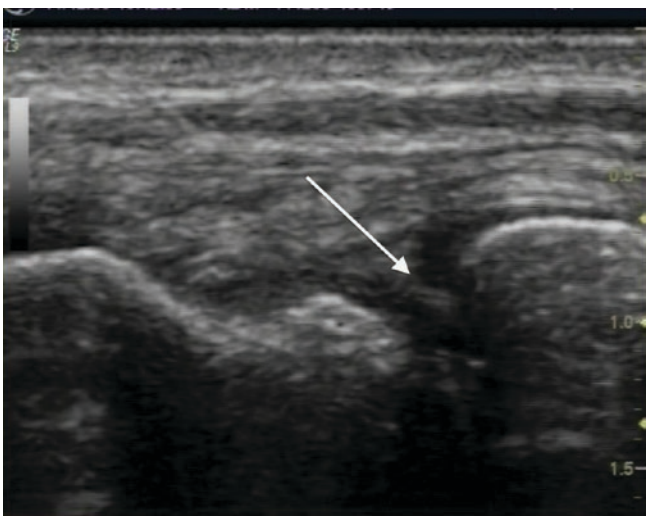


Fig. 6.8 Meniscoid syndrome with fibrotic and scar tissue in the radial collateral ligament proper

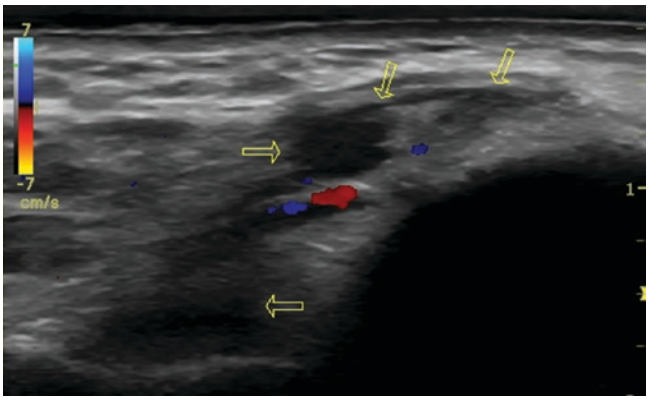


Fig. 6.9 Insertional tendinopathy of the common flexor tendon enthesis at the level of the medial epicondyle

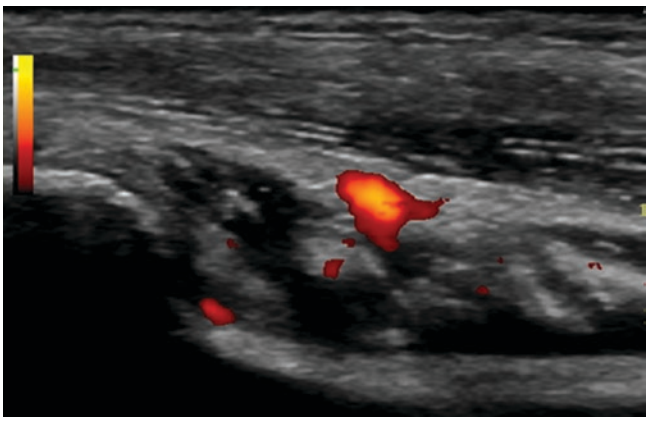


Fig. 6.10 Swelling with edema; the muscle components of the forearm extensors are shown on the power Doppler scan

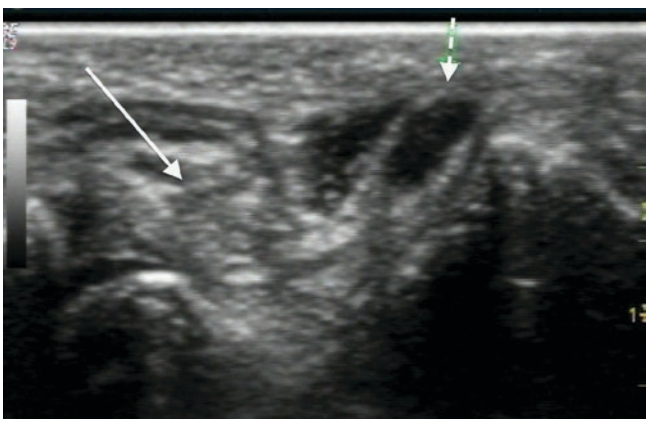


Fig. 6.11 Moderate hypertrophy of the medial head of the brachial triceps muscle (*arrow*) induces ulnar nerve compression and displacement (*dashed arrow*)

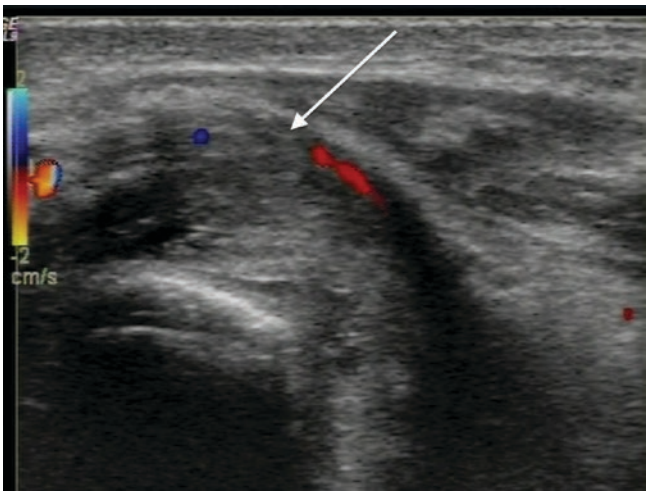


Fig. 6.12 Clearly evident periolecranon bursitis with both fluid and organized areas

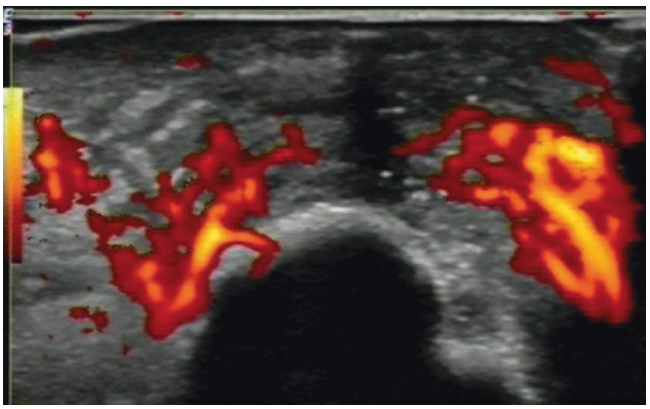


Fig. 6.13 Abscess formation in a swollen olecranon bursa

stabilized by a large band that inserts transversely into the ulna, providing a thick retinaculum (Fig. 6.15).

It has also been demonstrated that in abrupt overpronation and oversupination injury, the aponeurosis is directly responsible for tendon resection.

Full-thickness tears of one or the other tendon are common, and dynamic US with muscle contraction can help establish which is affected (Fig. 6.16).

Full-thickness tears with marked retraction of both stumps are associated with a large hematoma, whose differential diagnosis is with distension of the bicipitoradial bursa (Fig. 6.17a, b).

The two tendons often give rise to Kiloh-Nevin syndrome, which involves compression of the anterior interosseous nerve, a deep branch of the median nerve that courses in this area.

The biceps tendon runs centrally, parallel to the brachial artery.

Two further tendons that, albeit rarely, undergo degenerative or traumatic changes are the brachial tendon (Fig. 6.18), which runs deep under the biceps tendon and inserts on the ulnar tuberosity, and the anconeus.

The accessory anconeus muscle is a further anatomical variant. It runs above the ulnar nerve retinaculum in the cubital tunnel and often induces nerve compression (Fig. 6.19).

Dynamic US is the technique of choice to follow up tendon transplants, especially those due to full-thickness tears of the biceps tendon, which is usually replaced with the peroneus brevis or the posterior tibial tendon (Fig. 6.20).

Color and power Doppler are key imaging modalities, because they demonstrate the rich vascularity related to the neoangiogenesis associated with the repair process, reflecting normal graft take (Fig. 6.21).

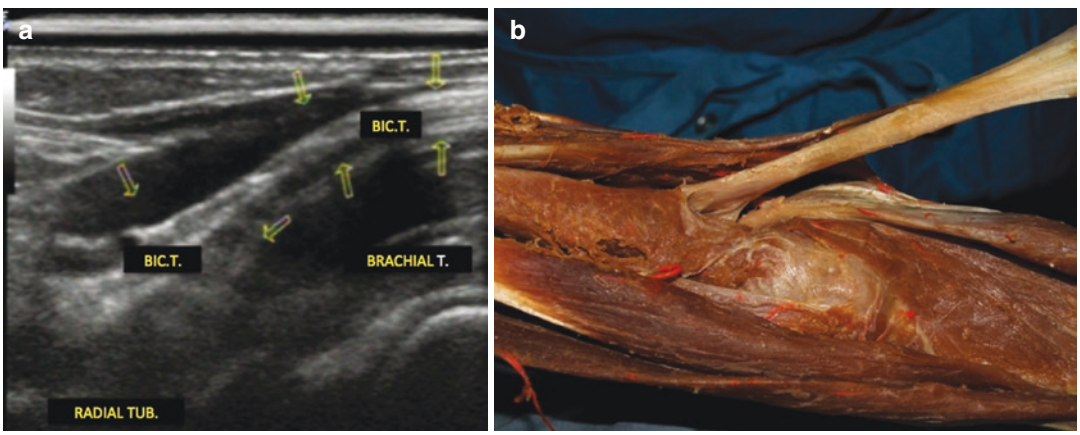


Fig. 6.14 (**a**) Clear double distal insertion of the brachial biceps: the upper portion is constituted by the long head and the lower part by the short head, both inserted into the radial tuberosity. (**b**) Same finding in a cadaver



Fig. 6.15 Anatomical cadaver study: the retinaculum or aponeurosis that stabilizes the distal biceps insertion



Fig. 6.16 Partial tear at the distal insertion of the short head of biceps; the long head insertion, at a still more distal site, is unaffected

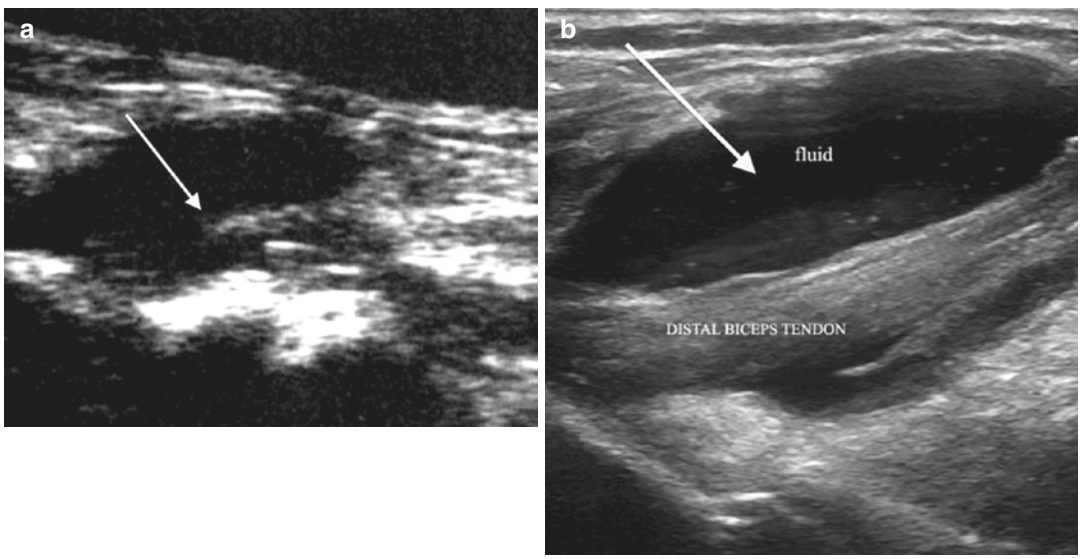


Fig. 6.17 (**a**) Clear hematoma with biceps tendon retraction (both short and long head) due to complete rupture. (**b**) Normal distal tendon insertion with marked bicipitoradial bursa distention

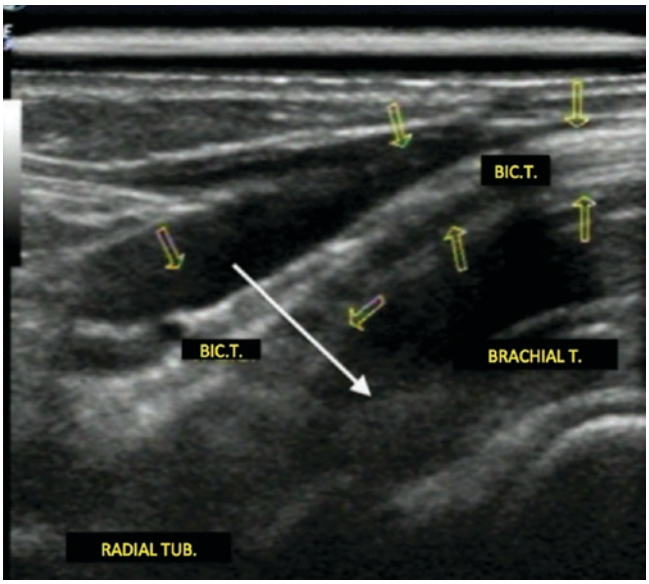


Fig. 6.18 Anatomical evidence of brachial tendon insertion on the ulnar tuberosity

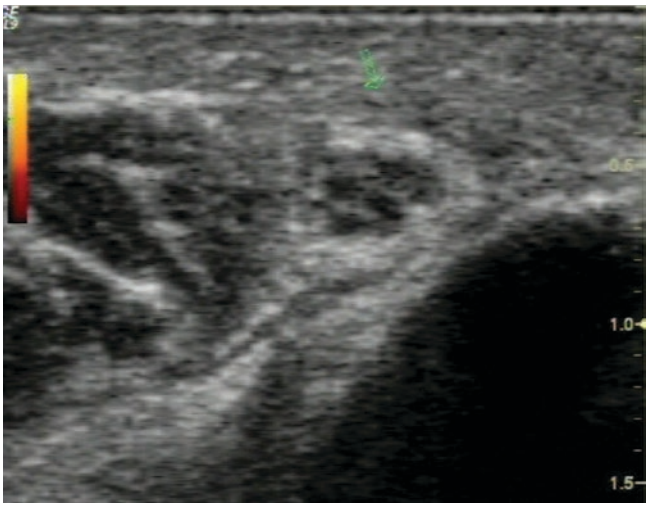


Fig. 6.19 The accessory anconeus muscle impinges on the course of the ulnar nerve

Another valuable US technique is elastography, which enables examination of tendon tension at the enthesis in patients with tendinopathy secondary to partial- or full-thickness tears and in those with tendon transplant (Fig. 6.22).

Color and power Doppler are also useful to monitor any calcification processes induced by drug treatment at these sites.

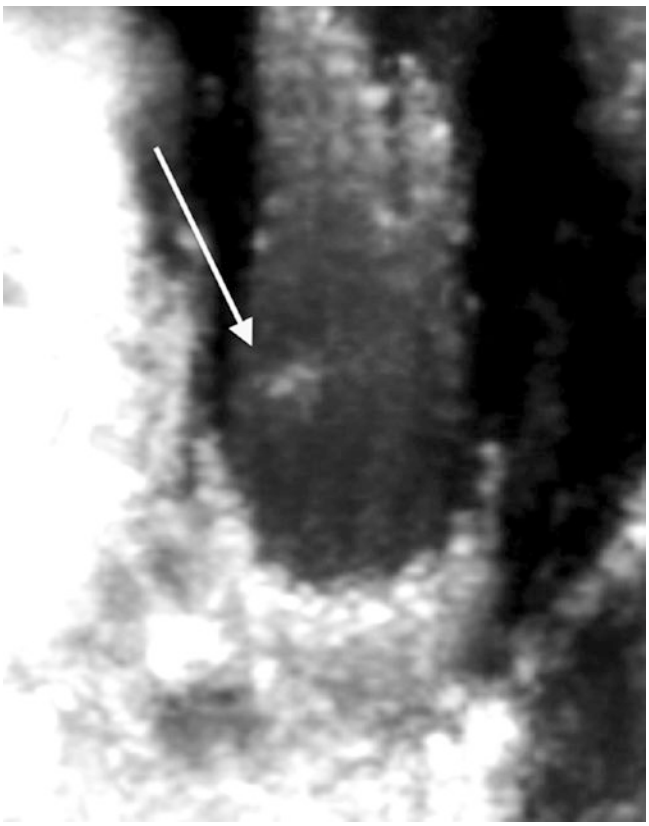


Fig. 6.20 3D reconstruction of posterior tibial tendon transplant at the insertion of the brachial biceps tendon

6.1.2 Capsuloligamentous Changes

Anatomically, the elbow includes three major capsuloligamentous compartments: lateral, made up of the radial collateral ligament proper (Fig. 6.23) and the radial ulnar collateral ligament; medial, made up of the five fiber bundles constituting the ulnar collateral ligament (Fig. 6.24); and an intra-articular compartment consisting of the annular ligament, which surrounds the ulna and radius, ensuring elbow joint stability.

US imaging provides accurate information on lesions of the radial and ulnar collateral ligaments, which are those most frequently affected (Fig. 6.25).

As noted above, high-grade lesions of the radial ligament involve directly the common extensor tendon, to which it is closely anatomically related (Fig. 6.26).

By contrast, MRI, especially MR arthrography, is indicated to examine the annular ligament, which requires 3D reconstruction (Fig. 6.27).

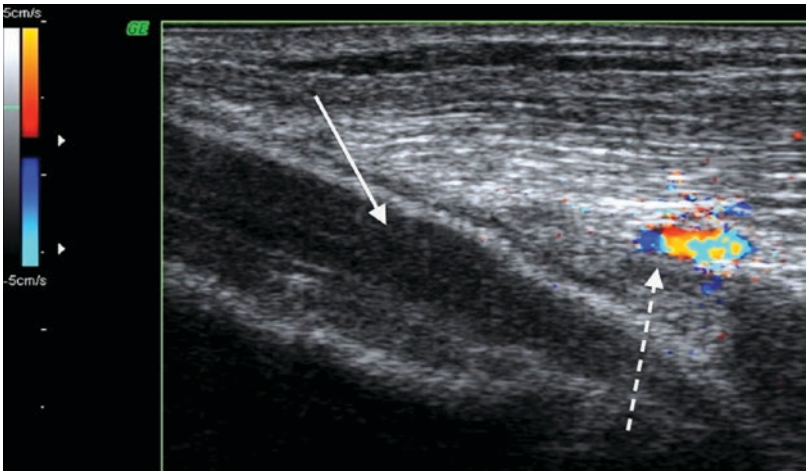


Fig. 6.21 Peroneus brevis tendon transplant replacing the brachial biceps (*solid arrow*). Neoangiogenesis related to normal graft maturation (*dashed arrow*)

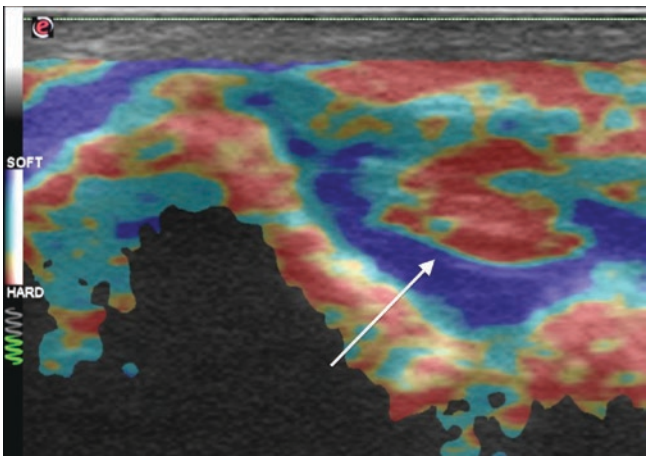


Fig. 6.22 Normal tension of the common extensor tendon at the level of the epicondyle

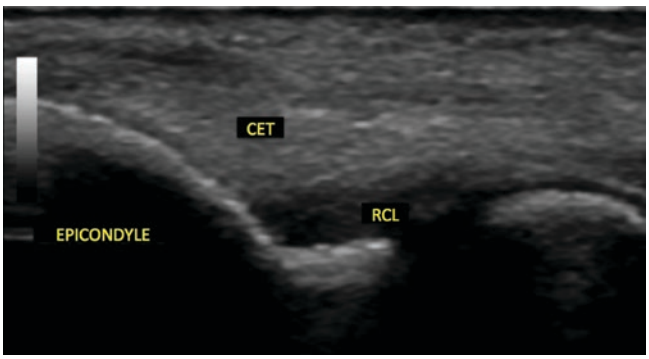


Fig. 6.23 Normal anatomy of the radial collateral ligament (RCL) proper. Note its close anatomical relationship with the common extensor tendon (CET) at the level of the epicondyle

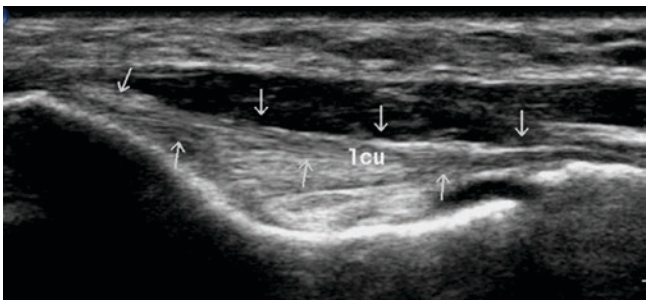


Fig. 6.24 Ulnar collateral ligament: its anterior bundle is indicated by the *arrows*

6.1.3 Nerve Pathology

The main nerve structures of the elbow are the median nerve (Fig. 6.28), which runs centrally on the volar aspect of the forearm, parallel to the brachial artery; the ulnar nerve (Fig. 6.29), which runs in the ulnar groove and the cubital tunnel; and the radial nerve (Fig. 6.30), which crosses from the posterior aspect of the arm to the antecubital fossa.

The deep motor branch of the radial nerve pierces the posterior interosseous nerve, constituting the arcade of Frohse (Fig. 6.31), which is formed by the posterior interosseous nerve itself, running between the superficial and the deep supinator muscles. The anterior interosseous nerve—the deep motor branch of the median nerve—constitutes the pronator arch (medial and ulnar heads of the pronator muscle) (Fig. 6.32).

Conditions involving the nerves at this site are often secondary to intrinsic lesions such as schwannoma and neurofibroma, which are effectively investigated by US. Color and



Fig. 6.25 Full rupture of ulnar collateral ligament and complete retraction at the level of the proximal third

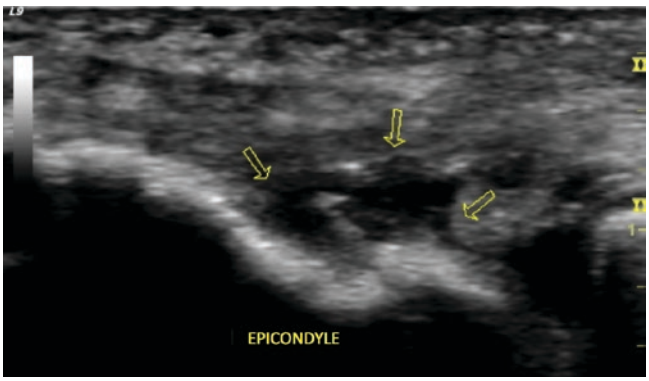


Fig. 6.26 Grade 3 lesion of the common extensor tendon with significant involvement of the radial collateral ligament proper

power Doppler provide accurate information on intrinsic vascularity (Fig. 6.33), whereas elastography is a valuable modality providing information on the elasticity of the neoplasm—whose signal is usually medium-high—prior to surgery (Fig. 6.34).

The assessment of extrinsic lesions, especially supinator syndrome and pronator syndrome, is more complex. These

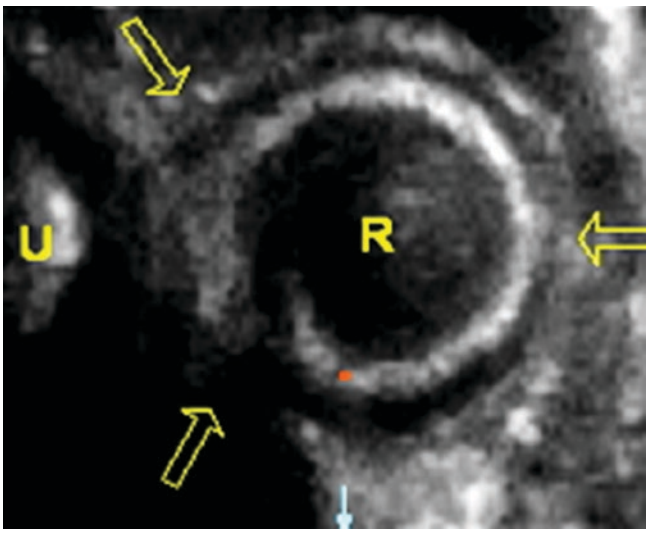


Fig. 6.27 3D reconstruction of annular ligament

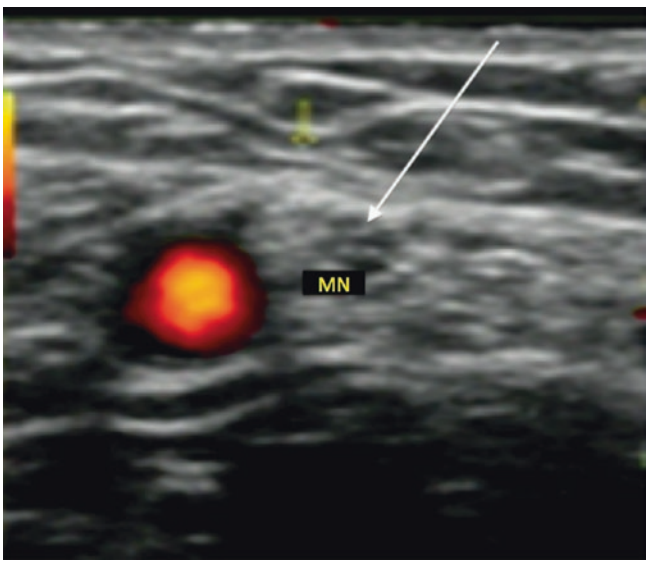


Fig. 6.28 Axial scan at the level of the ventral aspect depicting the median nerve (MN) lateral to the brachial artery

conditions are secondary to protracted mechanical stimuli such as pronation-supination, especially following muscle injury (which induces fibrosis and wall stiffening), and often fail to produce significant changes in nerve structures.

As mentioned above, another frequent nerve compression site is the course of the ulnar nerve in the cubital tunnel, due to contraction of the accessory epitrochlearis muscles, found in 10–12% of the world population (Fig. 6.35).

A frequent finding is the absence of the retinaculum at the level of the proximal region, before the ulnar nerve enters the cubital tunnel. This may be due to injury or to congenital causes and results in nerve instability and dislocation anterior to the medial epicondyle (epitrochlea).

In such cases, dynamic US is the imaging modality of choice (Fig. 6.36a, b).

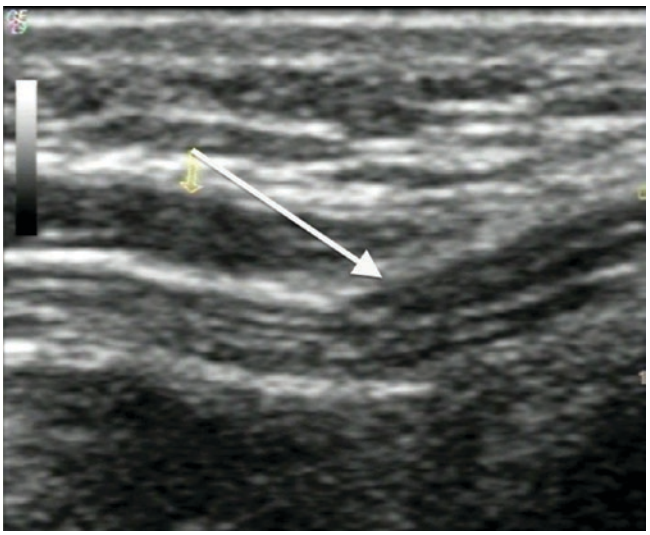


Fig. 6.29 Longitudinal course of the ulnar nerve above the cubital tunnel

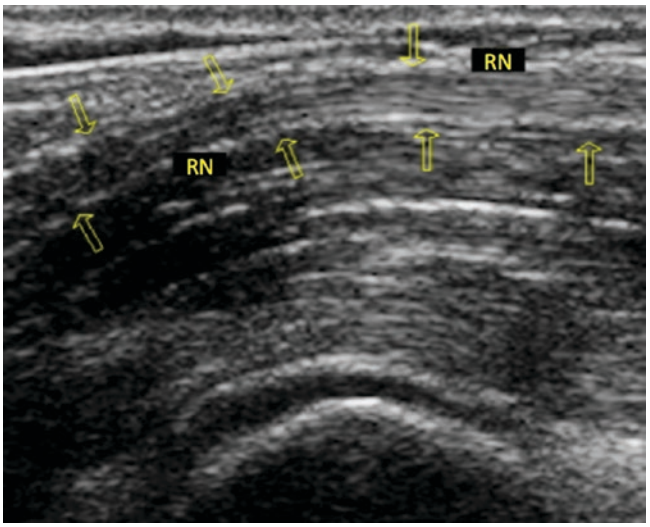


Fig. 6.30 Fairly superficial course of the radial nerve (RN) proximal to the arcade of Frohse

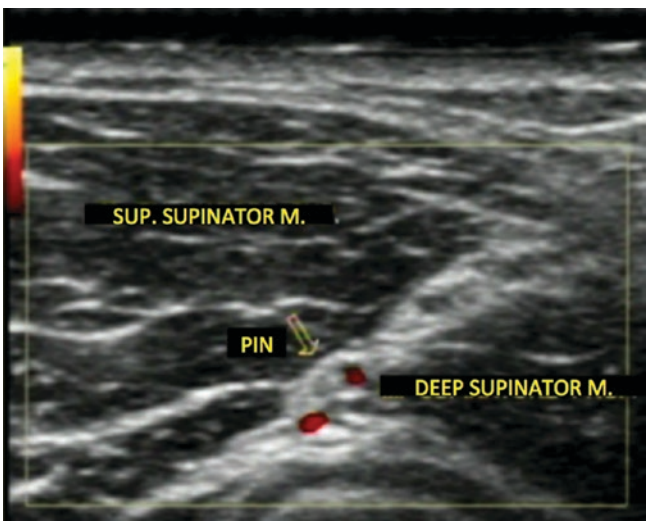


Fig. 6.31 Arcade of Frohse. Posterior interosseous nerve (PIN) running between the superficial and the deep supinator muscles. Axial scan

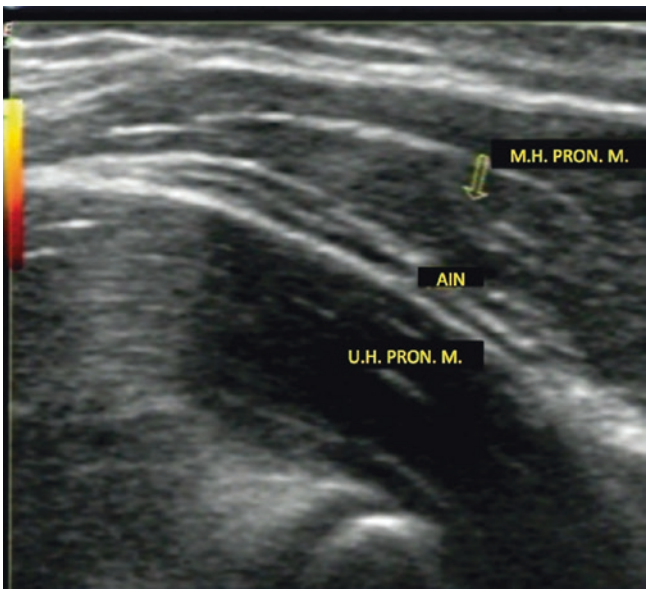


Fig. 6.32 Sagittal scan demonstrating the anterior interosseous nerve (AIN) between the medial and the ulnar head of the pronator muscle

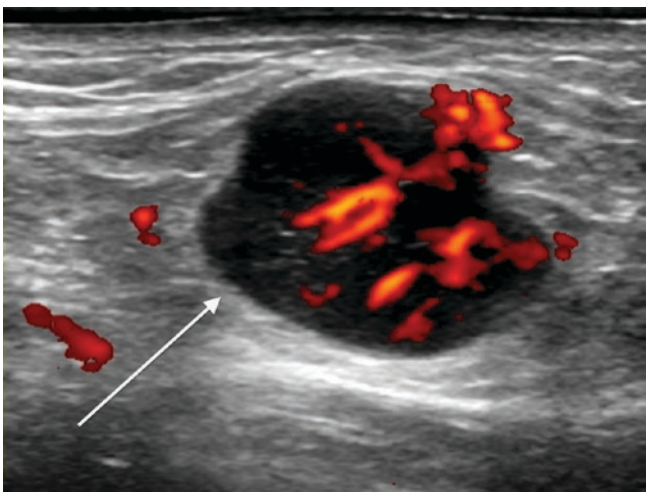


Fig. 6.33 Clearly evident ulnar nerve schwannoma. The power Doppler scan depicts its rich intrinsic vascularity

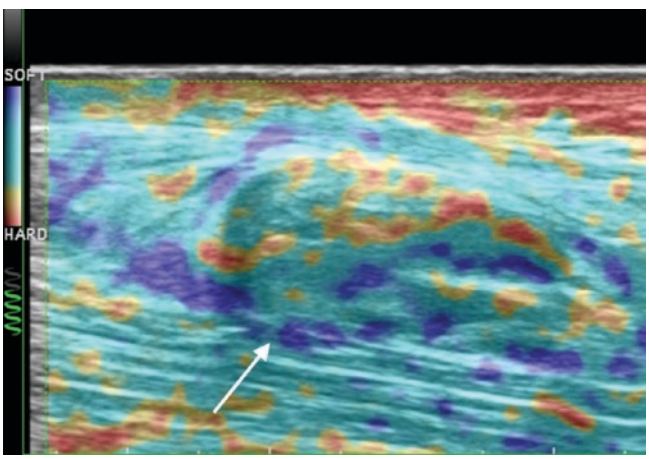


Fig. 6.34 Elastogram: the intermediate/high elasticity of this ulnar nerve schwannoma is a favorable prognostic factor for surgery

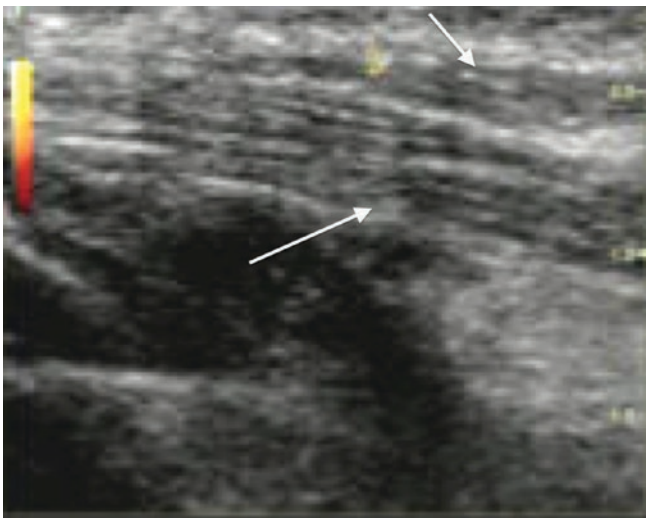


Fig. 6.35 Accessory epitrochlearis muscle compressing the course of the ulnar nerve

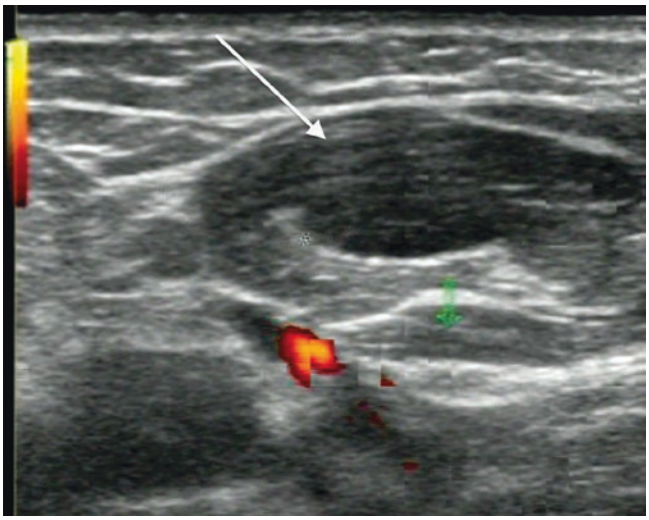


Fig. 6.37 Large lipoma at the level of the ventral elbow fold inducing marked compression of the medial nerve and brachial artery

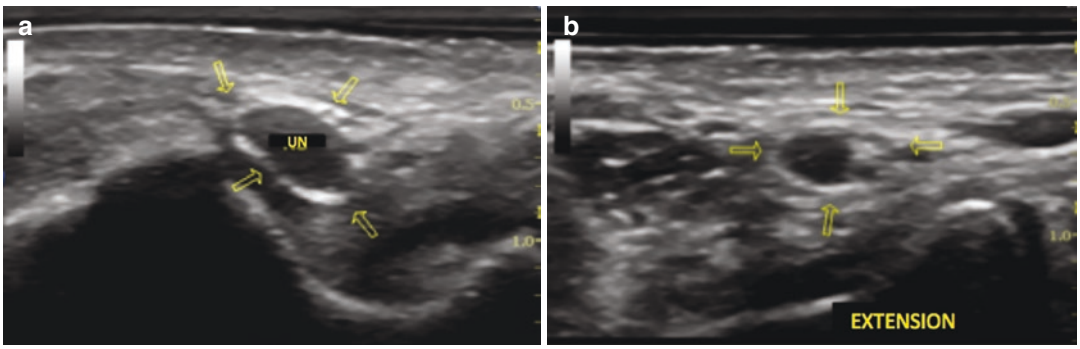


Fig. 6.36 (**a**) Axial scan at the level of the cubital tunnel with the elbow flexed. Marked edema involving the thickened ulnar nerve (UN) posterior to the medial epicondyle. (**b**) In maximum extension, the tendon undergoes complete anterior dislocation due to the absence of the retinaculum

6.1.4 Neoplastic Disease

Tumors involving the elbow joint are common, but are predominantly benign. Lipomas are the vast majority, possibly as a result of the frequent contusion injury sustained by adipose tissue, which is diffusely present around nerve structures for protection (Fig. 6.37).

As noted above, nerve tumors such as schwannoma and neurofibroma are also fairly common.

Other malignancies are less frequent and are predominantly liposarcomas.

US scanning completed by color and power Doppler is very accurate and is often the first imaging modality to detect tumors. CT/MRI, with intravenous contrast as appropriate, is then required to gauge their extension.

The elbow joint is prone to arthrosynovitis processes like synovial and calcific chondromatosis; they involve capsule distention, which is easily detected by US (Fig. 6.38).

However, US scanning cannot accurately establish the extension of such processes, which may be widespread and developed.

Finally, mechanical joint locking due to trauma and intra-articular loose bodies is best studied by CT.

6.1.5 Functional Imaging

For some years, functional dynamic US has been available at our institution. The examination involves imaging in contraction and relaxation and in flexion-extension, as appropriate, associated with elastography, which affords excellent functional follow-up assessment after injury (Fig. 6.39).

A further valuable preoperative approach is upright MRI with the patient standing, which enables dynamic assessment under limb compression or joint traction (3–5 kg) (Fig. 6.40).

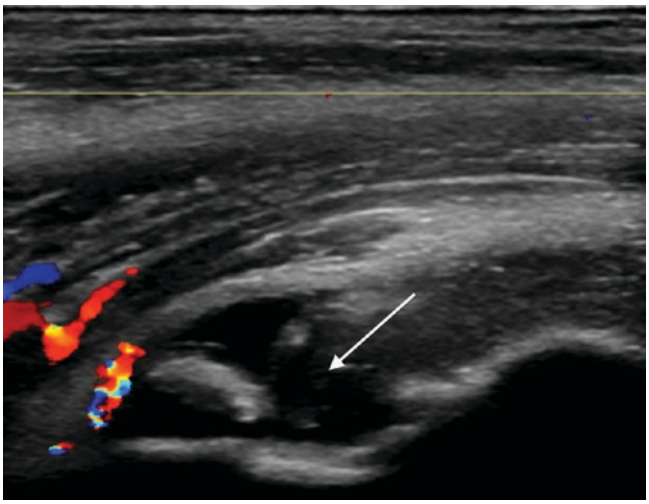


Fig. 6.38 Clear synovial chondromatosis of the anterior articular recess with capsular distention and multiple calcifications associated with a hypertrophic synovial pannus. Evident color Doppler reaction

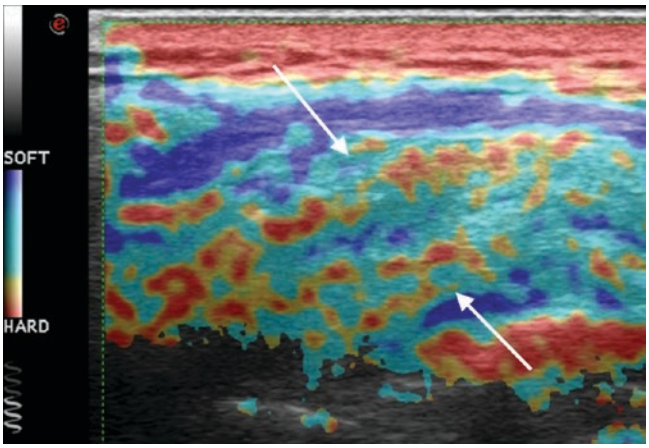


Fig. 6.39 Functional dynamic examination with a traction of 3 kg applied to the joint. The elastogram demonstrates normal tension of the distal biceps tendon in contraction

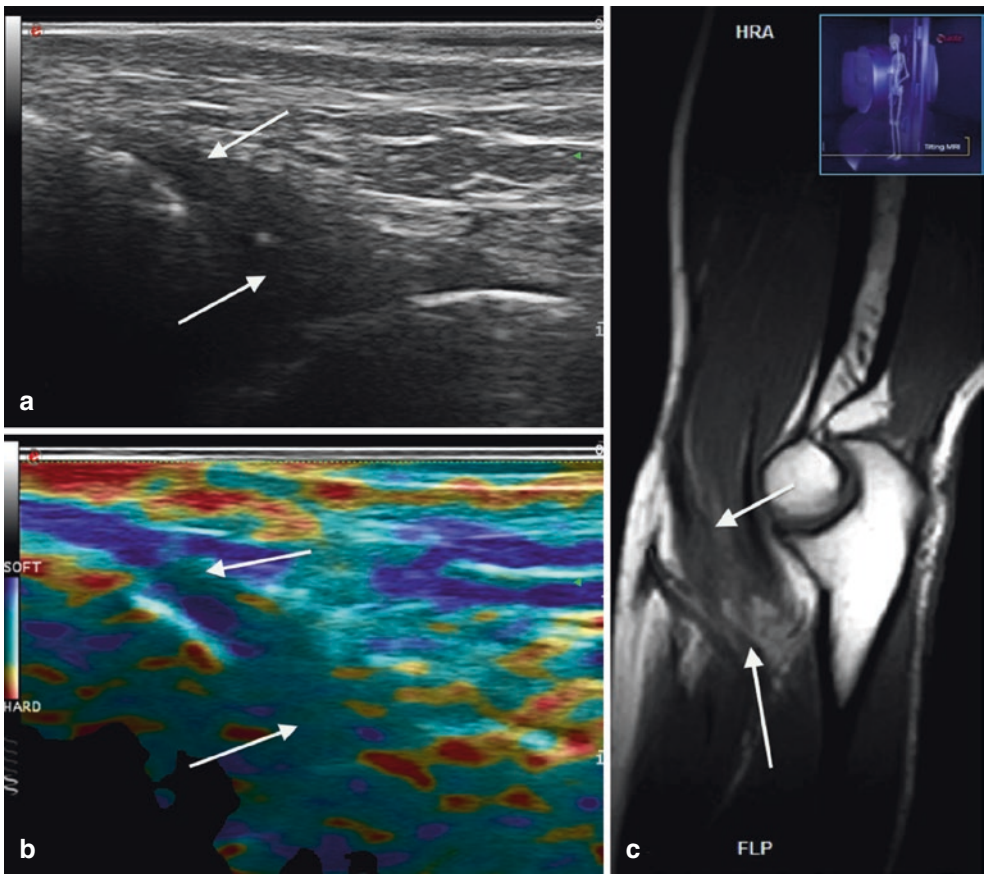


Fig. 6.40 (**a**) Sagittal B-mode dynamic scan in contraction documenting a full-thickness tear with retraction of the biceps tendon stump to the radial tuberosity; (**b**) same case investigated by elastography, depicting complete loss of tendon tension due to the full-thickness tear and presence of hematoma; (**c**) same case examined by MRI with the patient standing and a traction of 3 kg applied to the joint. Marked retraction of the biceps tendon to the distal insertion due to complete rupture

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Magnetic Resonance of the Elbow

7

Alberto Aliprandi and Chiara Mattiuz

7.1 Introduction

A thorough comprehension of elbow *pathological condition* derives from deep and clear knowledge of both joint anatomy and mechanism and kinematics of subluxation and injury. Although the elbow is one of the most congruous joints, traumatic dislocation of the elbow is the second most common dislocation after the shoulder with a reported incidence about 5.0 per 100,000 person-years (Schreiber et al. 2014).

It has been reported that in the US population the highest incidence of elbow dislocations is equal to 43.5% with an age ranging from 10 to 90 years old and sport related in 44.5% (Schaeffeler et al. 2013; Stoneback 2012).

Every day in their practice, orthopedics and radiologists have to come across with several elbow pathologies; unfortunately, precise comprehensions of the mechanisms that produce the patient symptomatology sometimes are still controversial and debated.

In this scenario, imaging can provide essential information to achieve a correct diagnosis and to set up the most appropriate therapeutic choice.

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7.2 Role of Magnetic Resonance Imaging (MRI) and Magnetic Resonance Arthrography (MRA): A Brief of Technique and Protocols

7.2.1 MRI

MRI is essential to obtain high-resolution images with excellent tissue contrast in multiple plain. MRI provides clinically useful information like an excellent depiction of muscles, ligaments, and tendons as well as the ability to directly visualize nerves, bone marrow, and hyaline cartilage. This allows evaluating the degree of soft tissue injury, to detect occult fractures and bone marrow contusion (Kijowski et al. 2005), and certainly can provide the correct timing in traumatic event. MRI serves also as an important adjunct to physical examination, being able to obtain information not easily obtainable even at surgery or arthroscopy and being particularly helpful in patients with subtle pain or chronic repetitive micro-traumatism history. However, MRI has some limitation, like a poor capability to discriminate bony fragments and mineralization depiction, intrinsically related to the basic principle of MR signal generation; for these reasons, in selected case, CT is still recommended.

Thus, MRI plays a crucial role to suggest the appropriate treatment to restore full joint function and to avoid disabling sequelae including recurrent instability, post-traumatic contractures, and arthritis (Linscheid and Wheeler 1965).

A correct evaluation of the elbow on MRI begins with proper patient positioning, which should maximize comfort and thereby minimize motion during examination. This can be usually achieved with the patient in supine position and the arm supinated along the side in anatomical position, but the main limit of this position is a reduction of image quality due to the distance between the arm and the isocenter of the magnet; this can lead to a decrease of signal-to-noise ratio and field homogeneity. Prone positioning with the arm over the head, the so-called Superman position, is often used, but its major limits are the discomfort reported by some patients. Patients with painful elbow may not be able to stay still in

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these two positions long, so MRI can be also performed with the arm 90° flexed: this position allows also performing MRI without removing elbow cast or restraints. The possibility of investigating the joint in different positions (i.e., flexed vs. extended or pronated vs. supinated elbow) with or without intra-articular contrast media injection may help to increase diagnostic confidence in certain conditions.

An ideal MR protocol should include sequences in coronal, sagittal, and axial planes. It is important to set up a field of view that includes the whole joint, from the distal humeral metaphysis to the insertion of the distal biceps tendon over the radial tuberosity. Imaging protocol should include both turbo spin echo (TSE) or gradient echo (GE) without fat-saturated T1-weighted sequences that help to delineate the morphologic features of bone structure; proton density-weighted sequences as well as fat-saturated TSE or GE T2/proton density-weighted or short tau inversion recovery (STIR) sequences could help identify subtle bone marrow and soft tissue edema, thanks to the high detection capacity of water content.

MRI after intravenous contrast media injection is usually performed to improve evaluation of the synovial membrane and to characterize bone and periarticular masses.

7.2.2 MRA

Administration of intra-articular gadolinium-based contrast material is not usually considered necessary in acute and subacute trauma timing. Normally, approximately 5–10 mL of diluted gadolinium (1:250) is injected in the joint space. Currently, ultrasound-guided injection is preferred over fluoroscopical injection due to the absence of ionizing radiations (Messina et al. 2016). Furthermore, ultrasound-guided injection has better accuracy over palpation guidance (Kim et al. 2013).

The main advantage of arthrography is the distension of the joint capsule, having proven to help in the assessment of recurrent instability of the elbow, of micro-instability in athletes, or in post-traumatic chronic instability before performing surgery.

Due to the presence and distribution of contrast media into the joint, MRA allows depicting cartilage tears and capsular abnormality and/or redundancy, especially in a flexed position. MRA is considered to be useful also in the characterization of ligament injuries and in the detection of partial tears of the collateral ligaments, in both subacute or chronic stages. Another advantage of MRA is that it can show loose bodies, chondral or osteochondral fractures, and synovial abnormalities. TSE T1 or PD-weighted sequences with or without fat saturation are used in most cases in conjunction with gadolinium injection to better assess the abovementioned structures. Conversely, inflammatory and degenerative changes are better visualized using T2-weighted or STIR sequences.

Figures 7.1, 7.2, and 7.3 show diagnostic capabilities and limits of MRI of the elbow.

Figure 7.1 shows posterior dislocation of radial capitellum. However, CT is not sufficient to demonstrate that there

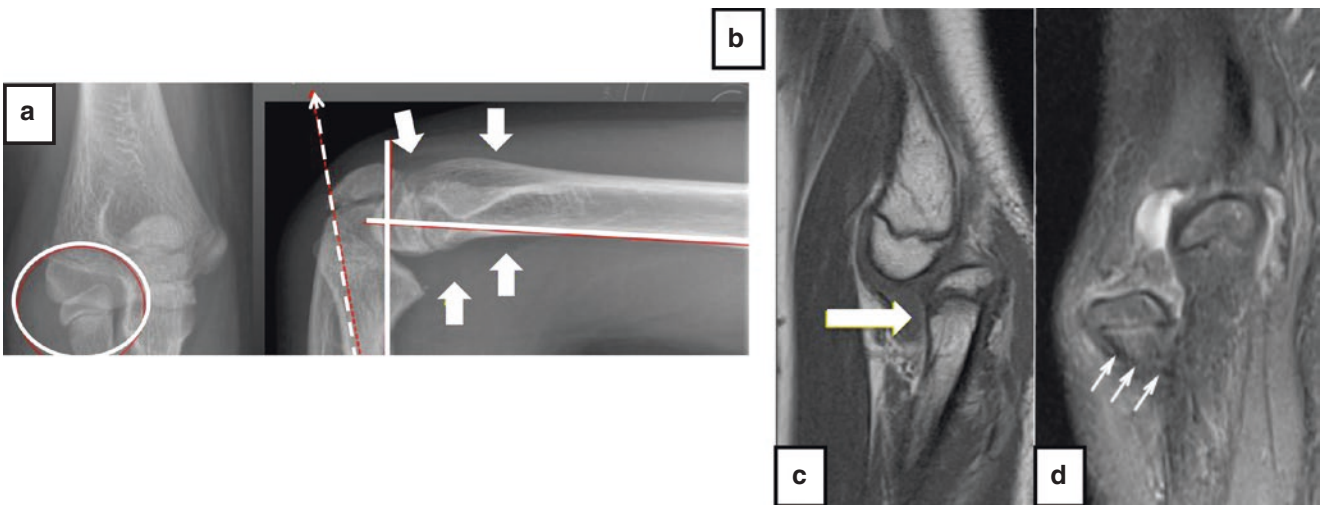


Fig. 7.1 Plain film of the elbow (**a**) in AP view; posterior luxation of radial head can be seen. Note how radial head overlaps the capitulum humeri (**b**) in a normal elbow; a line drawn along the anterior margin of the humerus (*the anterior humeral line*) and one along the long axis of the radius should intersect near the center of the capitellum (*black line*); in this lateral view, this relationship is not observed due to a posterior dislocation of the radius. Normally, lucency representing fat is present along the anterior surface of the distal humerus, and no lucency is visualized along its posterior surface. An elevated anterior lucency and/or a visible posterior lucency on a true lateral radiograph of an elbow flexed at 90° is described as a positive fat pad sign (*white arrows*) which represents the joint capsule distension, and it is the most important sign of intra-articular effusion; however, it does not allow to define the correct timing of dislocation. MR imaging (same patient). Sagittal view (**c**) TSE T1w shows posterior dislocation of the radius (*solid white arrow*). (**d**) T2 STIR sequence shows the absence of bone marrow edema, suggesting an old trauma

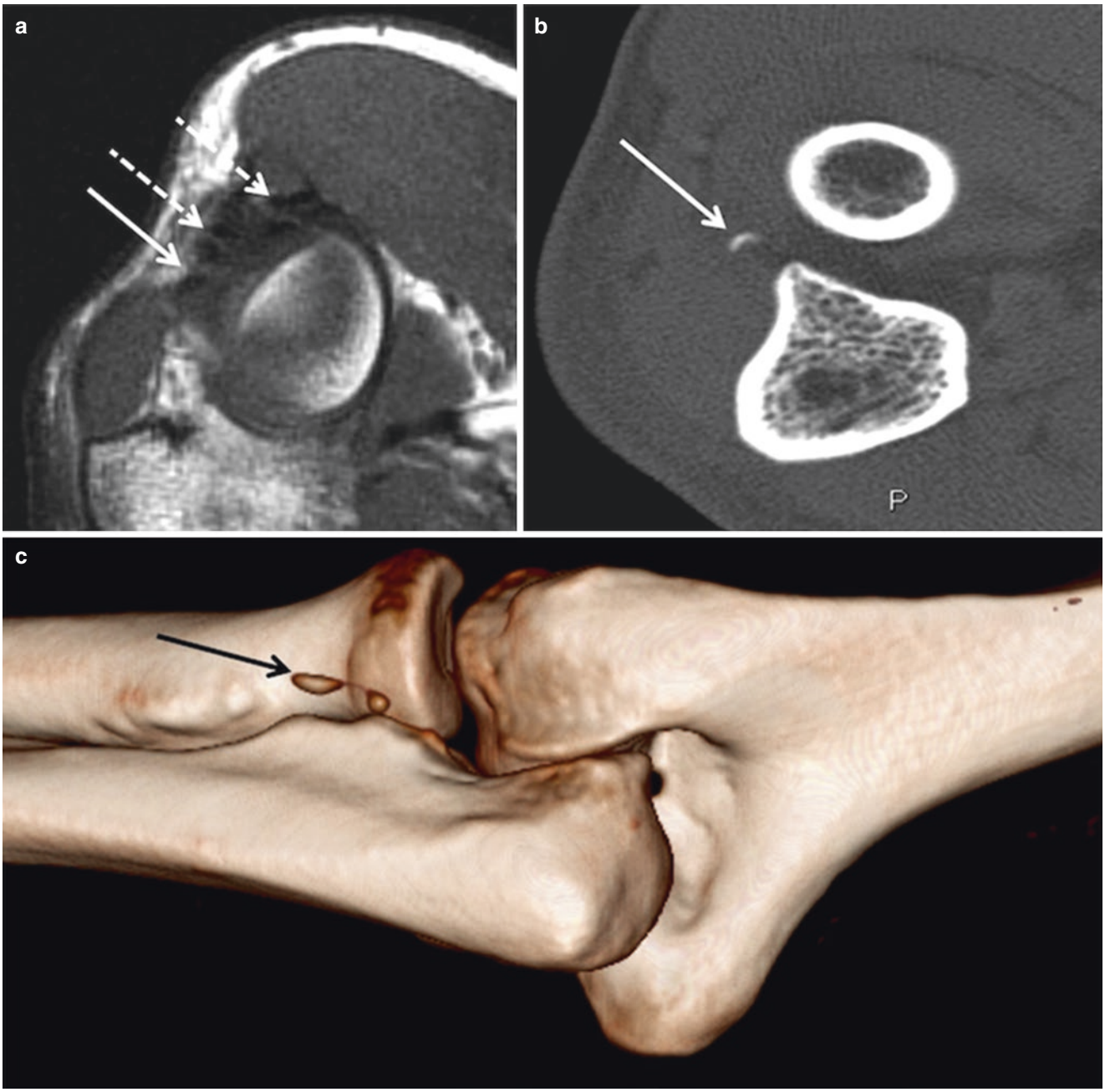


Fig. 7.2 shows MR arthrography TSE T1w axial sequence. (**a**) MR is a precious tool that detects soft tissue injuries related to trauma. But due to intrinsic technical characteristic, it may not discriminate tiny cortical avulsion from other structures like tendons, ligaments, or cortical portion of bone that are not pathological findings but normal structure. CT scan in axial plane with bone kernel reconstruction (same patient). (**b**) *White solid arrow* shows a hyperdense, comma-like image; CT allows to easily demonstrate the calcific nature of this finding; it represents a microscopic bone avulsion by annular ligament lesion fragment at its posterior insertion (**c**) CT with volume rendering reconstruction

are no signs of recent trauma (i.e., no bone marrow edema, no fluid collection), thus classifying the injury as chronic. In literature, it is reported that CT is highly sensitive in detecting tiny bone detachment and avulsion but is not adequate in evaluating soft tissues.

Figure 7.2 shows how MRI is not able to detect tiny cortical avulsions, as they cannot be differentiated from other structures with same low signal intensity like tendons, ligaments, or cortical bone.

Figure 7.3 shows acute elbow dislocation. Soft tissue and bone marrow edema is typical of this kind of trauma. MRI shows clearly soft tissue lesions (disrupted ligaments) but also a damage of posterior interosseus nerve confirmed by clinical examination.

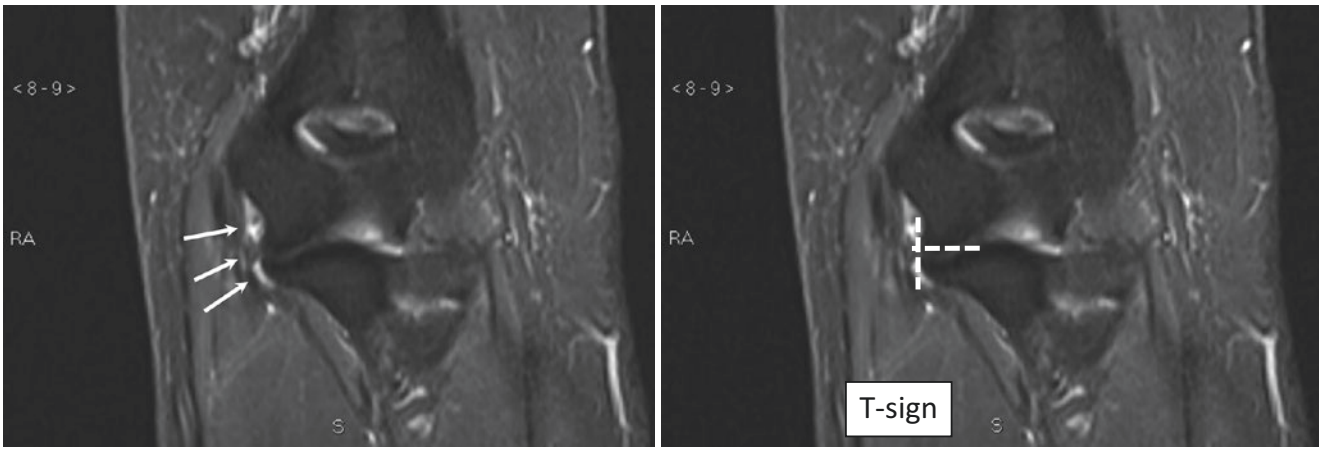


Fig. 7.3 MR arthrography. Coronal T1-weighted fat-saturated image demonstrates contrast media extending along the medial aspect of the sublime tubercle with disruption of the distal fibers of the ulnar collateral ligament (*white arrow*). A partial tear is seen creating the so-called T-sign

7.3 Imaging of the Elbow: How, Why, and What Are We Looking for?

Elbow stability is achieved by interaction between static (bone, tendon, capsule) and dynamic (muscles) components. In most to all cases, elbow instability is caused by a traumatic event, mainly a fall onto the outstretched arm, either with hyperextension or a posterolateral rotational mechanism. Elbow instability is classified according to (Englert et al. 2013; O'Driscoll 2000; Sheehan et al. 2013):

Time: acute, chronic, or recurrent (see above)
Direction of dislocation: according to the displacement direction of the radius and ulna in relation to the distal humerus (posterior, anterior, valgus, varus)
Type: with or without associated bony fracture

In this contest, it is not easy for both clinicians and imaging to distinguish a "pure" isolated pain condition from a micro-instability pattern. In this setting, the role of radiology is to confirm or to exclude the orthopedic diagnostic question by interpreting subtle indirect signs.

As discussed above, elbow instability is mostly caused by trauma. Clinical experience demonstrated that elbow stability is guaranteed primary by osseous integrity, i.e., the presence of at least 50% of coronoid process and 30% of olecranon articular integrity with or without ligament continuity. In some cases, however, patients report a painful syndrome characterized by a quite well stable joint. Usually this condition is related to joint micro-instability, and it typically represents a consequence of overload condition that occurs in sport or some works like painters, plumbers, construction workers, cooks, and butchers. As argued before, the choice of good arm positioning is important to investigate a precise structure: this is especially true for ligaments that usually appear hypointense in all sequences.

Collateral elbow ligament is best examined on coronal planes, while sagittal and axial planes can be used as confirmation. Semi-flexed position (20°–30° flexion) is particularly useful to demonstrate these structures; for example, the anterior band of ulnar collateral ligament is tight between 0° and 60° of flexion, while posterior band is tight between 60° and 120° of flexion.

In flexed abducted supinated (FABS) position, the arm is placed 90° flexion to achieve optimal evaluation of the biceps tendon fibers and enthesis, also helping to avoid magic angle artifacts. Also, pronation and supination may help displaying the insertion and tension of the annular ligament. Regarding the degree of ligament damage, there is a tight relationship between functional assessment and MR findings. This means that a grade I ligament injury with a preserved ligament functionality can be demonstrated on MRI as a focal area of increased signal intensity on T1w images, while a grade III injury with a complete loss of ligament functionality can be demonstrated on MRI like a complete tear associated with intra-/extracapsular effusion and hemorrhage (Figs. 7.4 and 7.5).

7.3.1 Lateral Complex

Lateral collateral ligaments (LCL), *annular ligament* (*AL*), and *lateral ulnar collateral ligament* (*LUCL*) together are the lateral complex, being the first not easily seen on standard MR due to its small size. Its injury is caused more frequently both by acute varus stress and less commonly by dislocation (Anakwenze et al. 2014; Seki et al. 2002). It is usually studied on coronal planes. *LUCL* is the most important stabilizer against posterior and rotatory shift of the forearm over the arm. It can be damaged by chronic varus overload, related to a work and/or sport activity, as results of transient external rotatory subluxation of the ulna on the

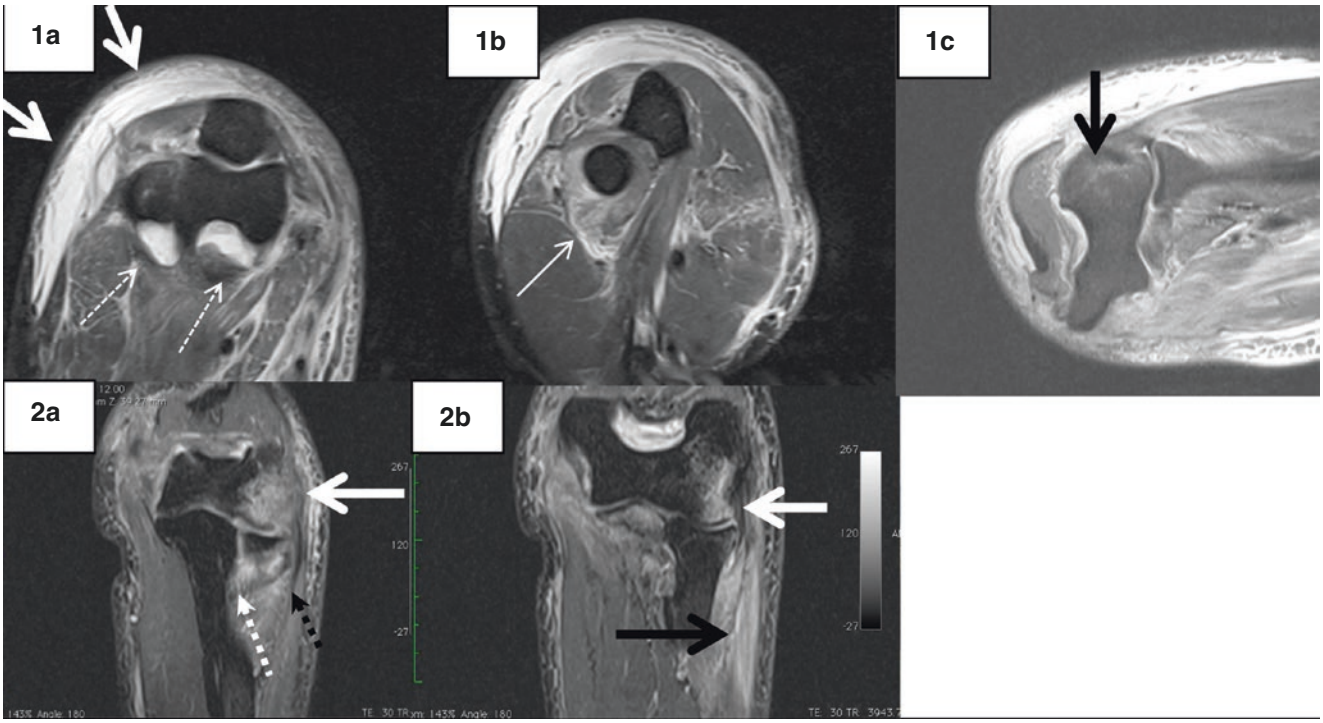


Fig. 7.4 MR imaging in acute (axial (1**a**, **b**) and coronal view (1**c**)) and subacute (20 days) (coronal view (2**a**, 2**b**)) evaluation. Patient had elbow dislocation reduced several hours after trauma. He developed joint instability and denervation syndrome due to a trauma over the posterior interosseous nerve (1**a**). MR performed 12 h after trauma shows soft tissue edema (*solid white arrows*) and bone bruise: extended superficial soft tissue edema associated with joint effusion (*dotted white arrows*) and of the medial aspect of joint capsule, lateral ulnar collateral ligament, and medial collateral ligament and (1**b**) supinator muscle edema (*white arrow*) (1**c**). Bone bruise is less intense (on the lateral epicondyle, *black solid arrow*) in comparison with later MR evaluation (2**a**, *white solid arrow*) (2**a**). STIR sequence. Twenty days after trauma, muscle signal intensity is increased (*dotted black arrow*) implying muscle denervation syndrome after nerve injury. Bone bruise of lateral condyle (*white solid arrow*) and on the anterolateral aspect of radial head is now well demonstrated; distraction and poorly defined lateral ulnar collateral ligament are also seen (*dotted white arrow*) (2**b**). Bone bruise of the coronoid process (*white slide arrow*); extensor carpi radialis brevis and supinator muscles edema with a normal aspect of muscle belly (*black solid arrow*). Note that atrophy and fatty replacement occur only in chronically denervated muscles

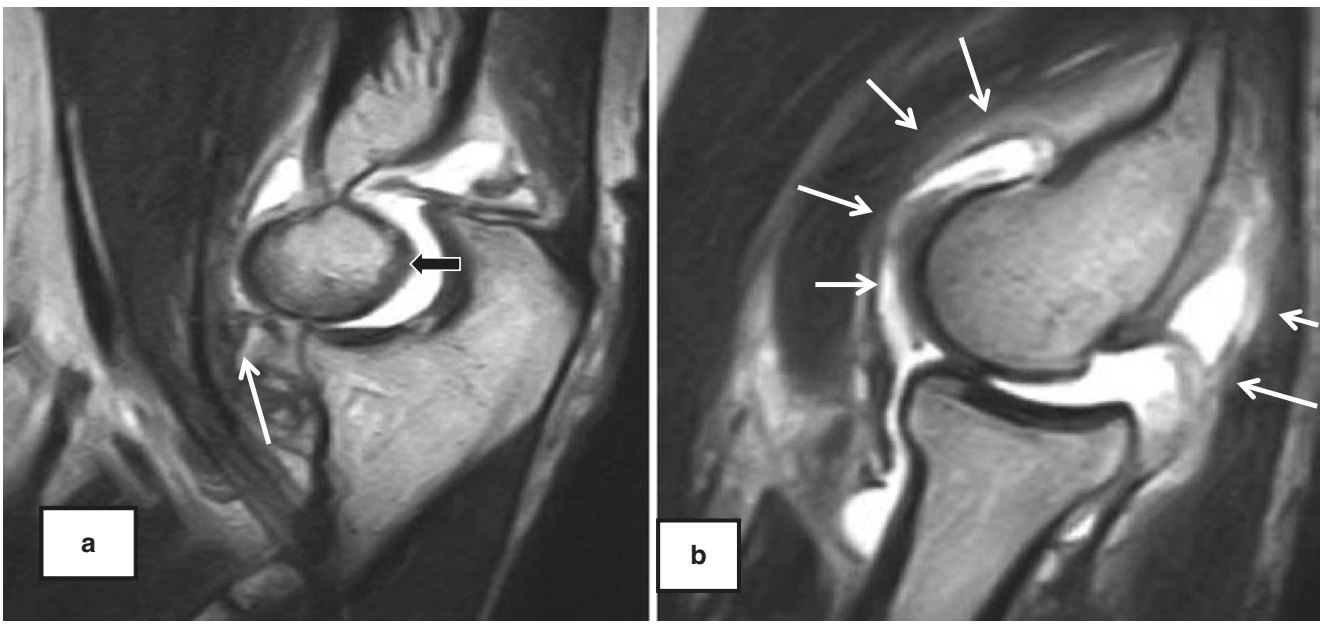


Fig. 7.5 MR arthrography. Sagittal T2-weighted sequences. (**a**) Stage II dislocation according to O'Driscoll classification. Coronoid is perched on trochlea with a coronoid bone fragment displaced (*white arrow*) and ulno-humeral gap (*black arrows*). Note that this can be observed only if patient is positioned with the upper arm extended; (**b**) anterior and posterior soft tissue disruption are well seen with MR examination. In this case, capsular redundancy is seen (*white arrows*). Posterior dislocation of radial head is also seen thanks to the upper arm in extended position

humerus, with posterior and valgus displacement, or less frequently as a complication after surgical treatment for lateral epicondylitis or radial head osteotomy. On coronal sequences, it appears like a thin, hypointense structure. The *AL* encircles the radial head and stabilizes the proximal radioulnar joint. Normally, in adulthood, the AL remains intact after minor traumas. It has assumed an increasing importance during the MR examination in patients with chronic lateral elbow pain, post-traumatic dislocation, and posterolateral instability. The axial plane enables identification of the annular ligament throughout its entire course around the radial head and its anterior and posterior attachments on the ulna (Mak et al. 2014); the anterior portion of the annular ligament is taut during supination, whereas the posterior portion becomes taut during pronation (Fig. 7a, e, b) (Regan et al. 1991). MRA is the best way to appreciate injury and can demonstrate laxity or pathological insertion of the capsule. However, in acute trauma, joint capsule may be distended, consenting to achieve an arthrographic effect, enlightening capsular laxity or ligament injury and improving the diagnostic interpretation, and avoiding injection of contrast media. Also CT arthrography may provide good results, although MRI is preferable due to the absence of ionizing radiations.

Multilayer tears or chronic ligament insufficiency usually requires a tendon graft reconstruction to restore elbow stability. Porcellini and coauthor reported the efficacy and the tolerability of this therapeutic approach (Merolla et al. 2014). Specific MR sequences (e.g., metal artifact reduction sequences, MARS) have been developed to avoid or limit metal artifacts, thus allowing the follow-up or a reassessment after trauma in surgery (Aliprandi et al. 2009).

7.3.2 Medial Complex

The anterior band of the MCL is the main restraint to valgus stress; as we mentioned above, its appearance is as a low-intensity structure best visualized on coronal plane. When it is damaged, it appears as an inhomogeneous and ill-defined structure with a high intensity on T1w images. Perilesional edema can be present in the acute phase, while in the chronic phase, fibrosis can be seen.

In adulthood, partial tears of the anterior band normally occur at its insertion on epicondyle and generate the so-called T-sign, meaning the evidence of contrast extension along the medial aspect of the sublime tubercle with disruption of the distal fibers of the ulnar collateral ligament. MRA is the best modality to recognize this kind of tears (Timmerman et al. 1994).

Another consideration is the possibility to perform MR under stress condition to better demonstrate the ligament partial tear, as normal position evaluation can underestimate the grade of ligament laxity.

The posterior band is best visualized on axial planes, where it contributes to the cubital tunnel origin. It is lax when the elbow is extended, so it cannot be easily recognized on coronal planes. MRI allows detecting and recognizing the presence of ligament injury, but the grade of MCL injury is better demonstrated with MRA. In fact, while MRI can easily show edema in an injured ligament, MRA can demonstrate infiltration of contrast media and hyperintensity signal on TSE T1w sequences detecting tears or avulsion. In some studies, sensitivity is 100% for full-thickness tears but is only 57% for partial thickness; other studies, performed with cadaveric model, found similar data in the diagnosis of MCL disruption (Gregory and Nyland 2013). MCL partial-thickness tears can be very difficult to see, especially when the deeper, undersurface fibers of the anterior bundle are detached. Tears can be demonstrated by the distal extension of fluid or contrast along the medial margin of the coronoid. Fat-saturated sequences can show bone marrow edema at the coronoid attachment.

Typically, MRI findings include:

T-sign: well demonstrated on coronal image in partial tears
Abnormal signal and aspect on the MCL, especially on the anterior bundle, best recognized on fluid-sensitive and fat-saturated sequences
Discontinuity of tendons in complete lesion with extravasation of contrast media in MRA
Abnormal signal intensity (presence of edema or hemorrhage) of surrounding soft tissue in complete tears
Bone marrow edema: as a result of ligament avulsion and/or severe stress injury (i.e., on the olecranon process in pitchers)

Typically, when the trauma is repetitive and with low energy, MRI findings include:

A thickened hyperintense anterior ligament bundle (on T1- or PD-weighted sequences) or hypointense on fat-saturated sequences
A traction spur
Micro-fractures at the humeral attachment site or at the ulnar coronoid
Hypertrophy of sublime tubercle (uncommon)
Synovitis

Medial epicondylar avulsion (most seen in young athletes) is the result of a chronic injury on a skeletally immature individual (little leaguer's elbow). In a little percentage (20%), the mechanism is acute valgus stress (arm wrestling or fall on outstretched hand). It can be better highlighted with gradient echo sequences on coronal planes, and it appears like a hypointense fragment in continuity with the ligament.

The sequelae of medial traction and lateral compression from valgus stress include MCL injury, common flexor tendon pathology, medial traction spurs, ulnar neuropathy, and osteochondritis dissecans. These conditions, as well as lateral collateral ligament injury and lateral epicondylitis, may be characterized using MRI.

7.3.3 Other Pathologies

7.3.3.1 Cartilage Wears

They are an important source of lateral or radio-capitellar compartment pain. These lesions typically occur in adolescent baseball pitchers, in tennis and squash players, and in gymnast due to chronic repetitive micro-traumatism that can lead to a chondral lesion, more frequently localized at the anterolateral aspect of radial capitellum. Although in the past the diagnostic value of CT arthrography and MRI has been proposed in the assessment of elbow cartilage, Dubberley et al. (2005) and Shahabpour et al. (2008) have found that neither CTA nor MRI was reliable or accurate enough. Also MRA has demonstrated a lack of sensitivity and accuracy, either with gradient echo sequences with or without short tau inversion recovery, probably due to the thinness of elbow cartilage on the articular surface (1–2 mm) (Theodoropoulos et al. 2012). Study on 3T systems may improve diagnostic accuracy over the conventional 1.5T systems. Panner's disease and osteochondritis dissecans (OD) are contrariwise better demonstrated both on MRI and MRA, which allow establishing the exact chondral defect extension, location, and fragment stability. OD is demonstrated as focal areas of low signal intensity on T1w and T2w gradient echo images. Two patterns can be distinguished: type I consists in a target-shaped area in which the external portion has a low signal in T1 sequences that becomes hyperintense in the inner part on T2w sequences and with an intermediate signal in the central part in T1w, and type II presents a homogeneous low signal intensity in T1 sequences that becomes hyperintense in T2w sequences. Stable lesion is surrounded in some case by patchy bone marrow edema, while instable lesion usually presents high signal (on fluid-sensitive sequences), rim, or cyst or as single/multiple focal lack of cartilage with the presence of loose body/bodies.

7.3.3.2 Nerve Injury

In the elbow, the main nerves are the ulnar nerve, the radial nerve and its deep branch (posterior interosseous nerve), and the median nerve and its branch (anterior interosseous nerve).

Chronic traction and compression in athletes result in radial, ulnar, and median neuropathy. Ulnar and radial nerve compression is the more frequent pattern observed in trauma, secondary to hematoma. MRI is helpful to distinguish the denervation signal of the muscles, although nerve compression is best evaluated using ultrasound. Entrapment syndrome is neuropathy due to a structural abnormality, such as compression, displacement, or traction of the nerve, or by an intrinsic abnormality of the nerve. The role of imaging is to confirm or support the diagnosis identifying primary or secondary signs (Miller and Reinus 2010). Normally, in the acute phase of denervation, the MRI is quite nonspecific, while in the early subacute phase (after 5–7 days), the main finding is muscular edema and a swollen appearance due to paradoxical hypertrophy. After 3 weeks, in the so-called late subacute phase, muscle atrophy can be observed, and it will remain as the characteristic finding in the chronic phase. Secondary signs of nerve entrapment may be focal flattening and proximal swelling that are expressed in an MR investigation as focal areas of signal hyperintensity. The muscle edema is better appreciated in T2w sequences, especially with fat saturation.

7.3.3.3 Biceps and Triceps and Other Tendon Injuries

Acute elbow trauma includes biceps tendon damage, and it is quite commonly related to sport activity (body builders) in the dominant arm or sometimes is seen in a fall trauma (snowboarders or football players) (Safran and Graham 2002). Less frequently, tendon disruption is due to tendinosis (Tomaino and Towers 2004).

In acute injury, a torn biceps tendon presents with abnormal signal intensity (fat-saturated sequences). Retraction may also be seen when associated to a lesion of the lacertus fibrosus. Fluid and hemorrhage can also be seen. Axial images extended from the musculotendinous junction to the radial tuberosity are commonly used in order to better assess the grade of tendon tear and to evaluate the lacertus fibrosus. As reported before, FABS view is the best way to underline these structures being related to the absence of magic angle and less discomfort for the patient. If tendinosis is present, tendon appears inhomogeneous and hyperintense. Occasionally, bicipitoradial bursitis is also seen.

Triceps tendon injury is uncommon, but it is reported to be increasing in professional high-impact athletes (i.e., weight lifters) (Mair et al. 2004).

MRI allows to detect abnormal tendon signal, thickening or retraction, soft tissue edema, bone marrow edema associated or not with bone trabecular injury, or fracture. Fat-saturated sequences allow to clearly define the rupture.

Lateral epicondylitis is referred to a common extensor tendon tendinopathy which may be observed in tennis players, between 40 and 60 years (Hayter and Adler 2012). This diagnosis is easily obtained with ultrasound examination. MRI has a role not for establishing diagnosis but for excluding other causes of lateral elbow pain in nonresponder patients to conservative treatment. The common extensor

tendon, best visualized on coronal image, is characterized by a thickened and inhomogeneous aspect, suggesting a loss of its fibrillar structure and an abnormal hyperintense signal on fluid-sensitive sequences; in some cases, a tear can be seen.

7.3.3.4 Plicae

Hypertrophic plicae are best known and recognized for pseudo-meniscus aspect, hypointense in every sequence (Awaya et al. 2001; Husarik et al. 2010).These redundant synovial folds are common among athletes, particularly throwing athletes and golfers, and may be an expression of impingement (Sanghi et al. 2007). MRI allows recognizing these structures with coronal and sagittal plane and a good knowledge of the normal dimension and signal intensity of plicae. Normally both T1w and T2w sequences and 3D sequences in sagittal and coronal plane may be used to correctly identify posterolateral plicae. Axial images are necessary to identify posterior plicae in the olecranon recess. In some non-diriment cases, however, MRA is needed, especially in locking elbow. MRA shows about 100% sensitivity for diagnosing plicae syndrome, thus becoming the modality of choice (Sanghi et al. 2007). In most asymptomatic elbow, plicae are thinner than 3 mm in caudo-cranial dimension (Awaya et al. 2001; Husarik et al. 2010), but in some cases, the thicker ones do not cause mechanical symptoms or pain as overlap in size between symptomatic and asymptomatic plicae exists. Thickening is produced by aging, chronic injuries, or inflammation, and these processes are related to the pain onset.

Conclusion

Elbow injuries are commonly encountered in the daily practice, and their complexity and clinical significance often are unrecognized at the initial evaluation. For this reason, elbow evaluation requires adequate and prompt assessment, especially in cases where the conventional radiography and CT are not conclusive. MRI is able to provide important information both for bone component and ligamentous structures allowing to orientate the orthopedic surgeon to the correct management of the patient. However, the use of a common language is crucial, also adopting the same classification systems, thus allowing to minimize errors due to an incorrect interpretation and to reduce the delay for intervention improving the therapeutic outcome.

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CT and 3D CT of the Elbow

8

Giancarlo Facchini, Alberto Bazzocchi, Paolo Spinnato, and Ugo Albisinni

8.1 Introduction

Computed tomography (CT) provides important information in the evaluation of the musculoskeletal system representing the completion of a diagnostic path started with conventional radiography (XR).

The introduction of CT for the musculoskeletal system dates back to the mid-70s (Wilson et al. 1978), but we have to wait until the introduction of multi-detector CT (Horton et al. 2002) to have a real progress in the diagnosis of musculoskeletal disease.

The main role of musculoskeletal CT is related to the study of bone. Bone contains elements (e.g. calcium), with high X-ray attenuation and sharp contrasts compared to surrounding soft tissue structures. Bone can be studied both in its cortical components and medulla components using appropriate contrast windows.

When the XR does not allow a clear diagnosis, CT plays a fundamental role, especially with the supplement use of multi-planar and three-dimensional processing images that allow a better assessment of the regional anatomy. These techniques are used especially for districts difficult to explore with XR or those with complex anatomy such as the elbow.

To get good reliable elaborations, correct acquisition is required. The main factors to be checked are patient position, layer thickness, interval between layers, and radiation dose. These parameters should be optimized with acquisition protocols to avoid possible artifacts that could affect the final image processing.

Thanks to these technological advances, CT provides information of various diseases of the elbow; you can obtain scan without contrast medium or studies with contrast medium (intra-articular or intravenously) depending on the diagnostic question.

The CT of the elbow is indicated for the evaluation of the following conditions:

- Trauma
- Bone and/or soft tissue lesions
- Degenerative disease
- Pre- and postsurgical evaluation
- CT-guided interventional procedure

8.2 Trauma

Traumatic injuries of the forearm and elbow represent about 15% of musculoskeletal injuries admitted to the emergency room every year (Pitts et al. 2008).

Radial head and neck fractures are the most common fractures in adults, representing 33–50% of all fractures of the elbow and approximately 20% of all elbow traumatic injuries (Aparisi and Aparisi 2013). The diagnosis is usually made by conventional radiography, and CT is reserved for doubtful cases, in cases of persistent pain or possible surgical planning.

The elbow stability depends on bone, ligaments, and cartilage. In most cases, a bone fracture is the cause of instability. However, if it is supposed a ligamentous or articular cartilage injury, CT does not allow a comprehensive evaluation and becomes indicated in the execution of an elbow MRI. The CT can highlight bone fracture less than 2 mm.

CT is performed more frequently in elbow suspected fracture to allow a correct classification of major injuries that require surgery. Multi-planar reconstructions allow orienting the image on all spatial planes, to assess the possible extension of the intra-articular fracture. When there are multiple bone fragments, CT becomes essential: three-dimensional

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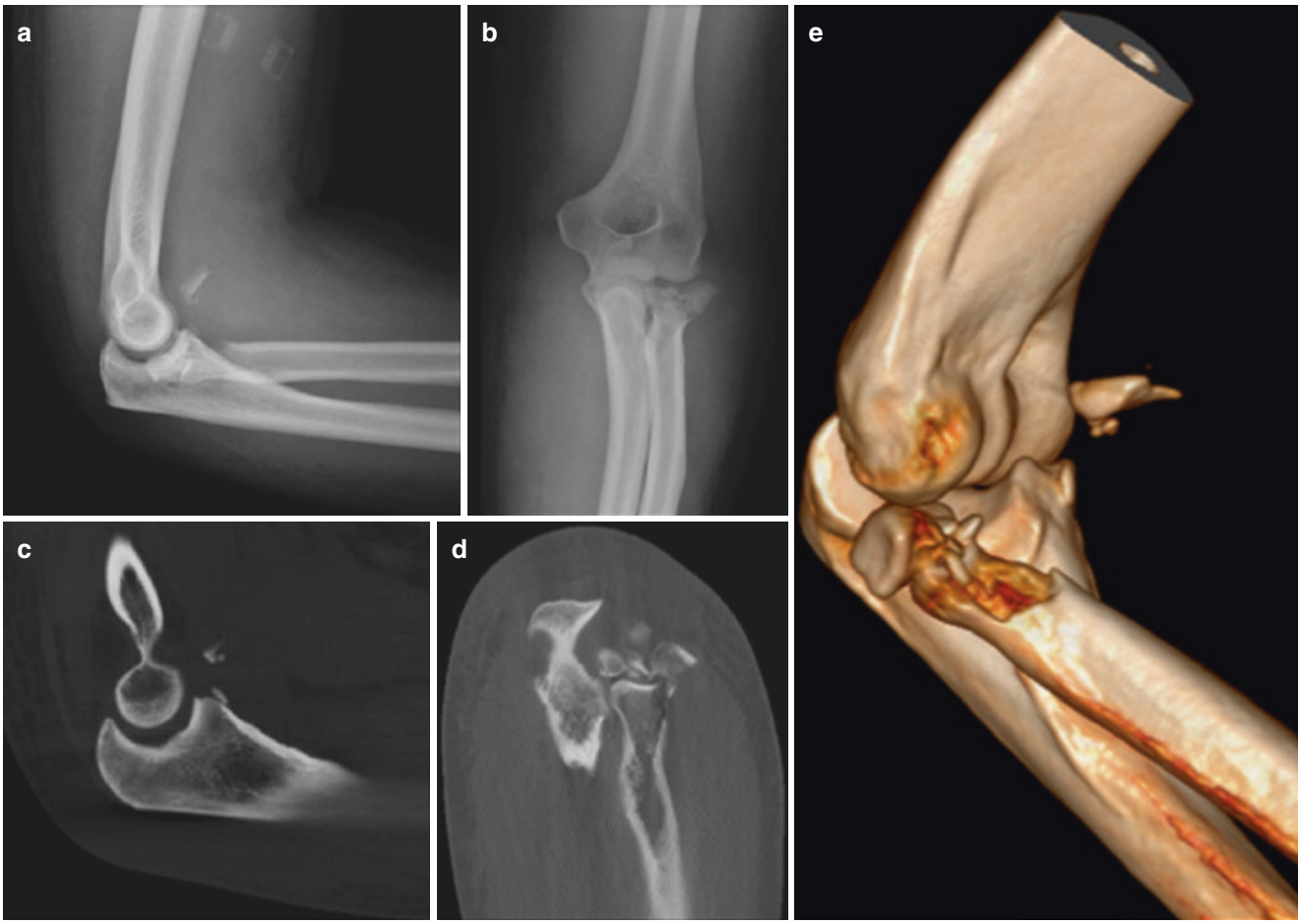


Fig. 8.1 A 50-year-old man with intense elbow pain after trauma. XR examinations (**a**, **b**) show the proximal epiphysis radius fracture, a bone fragment in the medial part of the elbow and the articular effusion. CT image reconstructions demonstrate the coronoid fracture and better visualize the comminuted fracture of the radial head (**c**, **d**). 3D CT image reconstruction better visualizes fracture extension (**e**)

(3D) reconstructions can obtain precise fragment assessment and show their position in space.

In radial head fractures, the diagnosis is usually made with conventional radiology; however, CT allows a radiological "dissection" of the elbow without bone overlapping with the most precise picture of surgical devices (Figs. 8.1 and 8.2).

3D CT improves diagnosis of uncommon but clinically important lesions as Essex-Lopresti fracture affects the radial head with the radio-ulnar dislocation and destruction of the interosseous membrane producing the so-called floating radius.

A proper assessment of the coronoid process fracture of the ulna requires the characterization of the lesion, assessing the size of the fragment, the degree of anteromedial facet involvement, and the potential involvement of the base of the coronoid. CT evaluation of the coronoid process is recommended, and early evaluation with CT is becoming routine. In assessing the coronoid process for the fracture, particular attention should be paid to the anteromedial facet (AMF). The AMF of the coronoid protrudes medially from the ulna metaphysis, widening the articular surface to act as a secondary stabilizer to varus instability. The AMF is vulnerable to strong varus stress because about 60% of the facet is not supported by the ulnar metaphysis. An untreated AMF fracture may lead to varus posteromedial instability because of

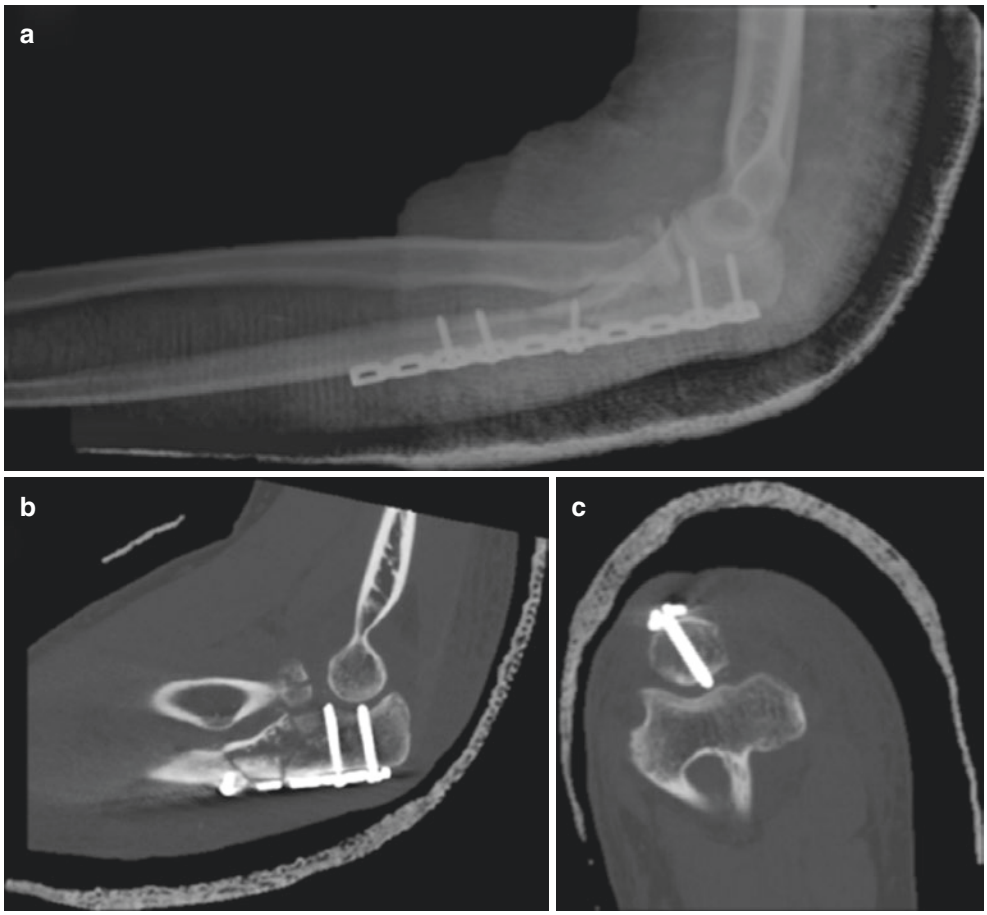


Fig. 8.2 A 46-year-old man submitted to surgery for fracture stabilization. XR shows the presence of the screws inside the joint (**a**). CT better demonstrates screws procidentia inside the joint space (**b**, **c**)

concomitant lateral collateral injury. For the accurate assessment of this aspect of multi-planar reformats (MPR) and volume rendering, 3D is necessary.

8.3 Bone and Soft Tissue Lesions

Bone and soft tissue tumors of the upper limbs are infrequent, and only 1% are located at the elbow (Pritchard and Dahlin 1985).

Diagnostic imaging is a crucial component of the workup of a patient with a musculoskeletal tumor of the elbow and should proceed in an organized fashion. Initial imaging often includes radiographs in orthogonal planes to localize and characterize a lesion. Although soft tissue lesions may not be seen on plain radiographs, at least one set is usually taken to look for calcifications, erosion into adjacent bone, or other features. Bone lesions must be evaluated for location of lesion within the bone, size, margin, zone of transition, periosteal reaction, mineralization, and number of lesions. For lytic bone lesions, the Lodwick classification (Lodwick et al. 1980] is commonly used.

Cross-sectional imaging (CT) is able to provide crucial information regarding size, tissue characteristics, and anatomic relationship to other structures of a lesion. Computed tomography (CT) is ideally suited for evaluation of the characteristics of a bony lesion, but may have some usefulness in evaluating soft tissue masses, particularly if there is periosteal reaction or osseous erosions adjacent to the soft tissue mass.



Fig. 8.3 A 14-year-old child with nocturnal elbow pain. XR does not show any pathology sign (**a**). CT images demonstrate an osteoid osteoma nidus on the distal humerus (**b**, **c**, **d**)

The CT with the use of contrast medium can highlight areas of pathological enhancement describing the limits of the tumor and the extent of bone. The multi-planar techniques and 3D reconstructions can allow proper planning of surgical approach and a simulation of the prosthesis or allograft transplantation to be used to replace diseased tissue removed (Fig. 8.3).

Because bone and soft tissue sarcomas have a tendency to metastasize to the lungs, CT of the thorax is imperative in the evaluation of these patients, although it does not need to be performed before biopsy. In the case of a metastatic lesion from an unknown source, chest, abdomen, and pelvis CT should be obtained in addition to common laboratory studies.

8.4 CT Arthrography

Elbow arthrography is less commonly performed compared with arthrography of the shoulder and hip but still remains a diagnostic exam that provides important information in certain diseases of the painful elbow.

Magnetic resonance arthrography has essentially replaced CT arthrography due to its superior ability to differentiate soft tissue and the absence of ionizing radiation. CT arthrography is an alternative for patients with pacemakers, metal device that are not compatible with magnetic resonance imaging and/or for patients allergic to MRI contrast.

The indications of CT/MRI arthrography are the ulnar collateral ligament injury, chondral lesions, and the presence of intra-articular bone fragments (Delport and Zoga 2012).

8.5 Degenerative Pathology

Osteoarthritis is much less common in the elbow than in the other upper and lower limb joints. Causes of osteoarthritis include overuse injuries, osteochondritis dissecans, osteochondromatosis, crystal arthropathy, sequelae of septic arthritis, and trauma.

Traumatic injuries of the elbow, which represent the main cause of degenerative disease, may progress to osteoarthritis due to damage to the articular cartilage or fracture incomplete repair, malunion, instability, and/or incongruity of the articular surfaces.

Although it is not a weight-bearing articulation, the elbow is subject to considerable forces that can reach 0.3–0.5 times the weight of the body at the humerus-ulnar articulation or three times at the humero-radial articulation during daily activities (An et al. 1984).

In literature, there are few studies that determine the incidence of degenerative disease of the elbow. It is recognized that the main causes are post-traumatic lesions: osteoarthritis secondary to intra-articular fracture of the distal humerus, to a fracture of the radial head, to a fracture of the ulna proximal, or to instability of the elbow.

Plain radiographs are the first-line study, but CT is the gold standard test for evaluation of osteoarthritis. Three-dimensional reconstructions are very useful in assessing the changed anatomy and the cause of osteoarthritis.

Role of CT:

a. determine the location and severity of osteoarthritic lesions and the involvement of the ulno-humeral joint and/or humero-radial joint
b. assess the adequacy of the articular surfaces
c. detect any filling of olecranon and coronoid fossa by foreign bodies
d. analyze deformities such as metaphyseal consolidation, intra-articular deformity, and severe morphological abnormalities related to an injury in childhood
e. assess any periarticular ossifications

These assessments allow the surgeon to make the best therapeutic choice (Chadwick and Nicol 2000).

8.6 Pre- and Postsurgical Evaluation

CT is routinely performed for the evaluation and preoperative planning of patients undergoing elbow surgery. CT can be used to evaluate bone as well as soft tissues. CT with contrast medium can visualize arteries, veins, and nerves around the elbow and their spatial relationships to the elbow fracture and fragments. CT can be very useful to determine preoperative decision making (choice of the type of prosthesis, metal devices to use) and planning the surgical pathway.

3D CT data allow perfect construction of custom-made prosthesis.

8.7 CT-Guided Interventional Procedure

In the past few decades, the use of surgery in the treatment of lesions in many anatomic sites has been progressively replaced by less invasive CT-guided percutaneous procedures. A reduction of invasiveness is desirable in all locations but especially when lesions occur in joints and other challenging sites. In 1992, Rosenthal et al. (Rosenthal et al. 1992) were the first authors to introduce radio-frequency thermal ablation (RFA) for treatment of OO, with excellent results. Since then, this procedure has gained more credit, and its use has been extended to the treatment of other lesions (Ruiz Santiago et al. 2011; Rybak 2009) and in children (Albisinni et al. 2005).

In the years 2002 through 2012, about 800 patients underwent RFA for OO of all sites at the Rizzoli Orthopaedic Institute. In our series of about 900 OO cases, the elbow location represents about 4% of all cases (Albisinni et al. 2014). To be performed safely and effectively, interventional procedure of elbow (thermal ablation, needle biopsy, etc.) requires special attention to many aspects. The patient's position has to be carefully studied because (a) it can affect the presence of overlapping of bony structures and (b) can prevent to perform properly the interventional procedure. Moreover interventional procedures use needles that produce metal artifacts that can prevent a correct view of the structures to be treated. All these pitfalls can be reduced or avoided with proper planning. The path of the needle electrode should exactly reproduce what was planned on the CT scan using multi-planar reconstruction. Access point selection is crucial to obtain good results (Fig. 8.4).

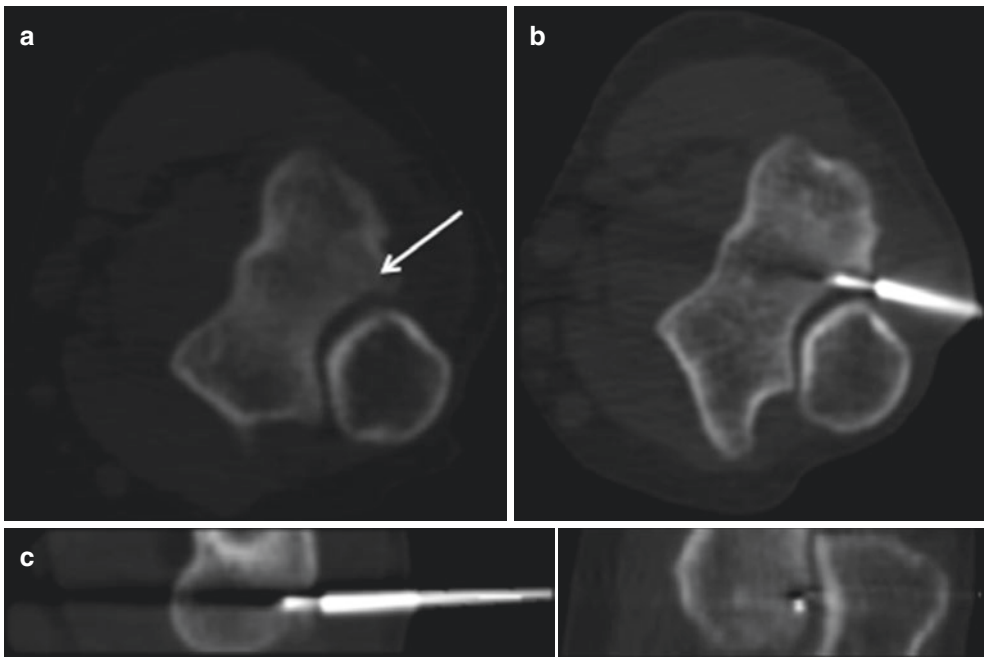


Fig. 8.4 The same young patients; thin-slice CT scan demonstrates the OO of the distal humerus (**a**) and allows to plan thermoablation. It's mandatory to evaluate the final position of the radio-frequency electrode (**b**) using multi-planar reconstruction before starting thermoablation (frontal, sagittal reconstruction) (**c**). The interventional CT images are not comparable with the CT diagnostic scan because the elbow position is different to better carry out the interventional procedure

8.8 Dual-Energy CT

Ten years ago, dual-energy CT (DECT) started working (Genant and Boyd 1977). Which could be future possible advantages? Currently, DECT stands as the frontier for metal artifact reduction and radiation dose reduction. DECT requires no additional radiation and provides significantly enhanced image acquisition. When considered along with its other capabilities, DECT is a promising new tool for musculoskeletal radiologists.

Conclusion

Imaging evaluation of patients with elbow pathology requires deep knowledge of anatomy, possible physiological variants, diseases, and methods used to perform the exam. The information gathered by history and clinical examination directly influence the study performed by the radiologist.

Multi-planar and three-dimensional processing images allow a better assessment of the elbow anatomy. The technological advancement and dose reduction of CT make radiographs increasingly isolated, leading CT to main role in diagnostic imaging.

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Rehabilitation Protocols: Are They Useful?

9

Andrea Foglia and Paolo Bizzarri

In neuromusculoskeletal rehabilitation, treatment protocols have always had wide dissemination and considerable importance in the daily clinical practice of many practitioners.

What is meant by a protocol? The term *protocol* indicates "a prescriptive sequence of well-defined conducts. Protocols are rigid and legally binding (Cartabellotta 2008) instruments which aim to guarantee the provision of specific services".

The advantages of adopting such conducts are undeniable. The use of predefined treatment plans based on the individual patient's diagnosis, as established by the clinician, allows for systematic and more precise rehabilitation interventions, minimising the possibility of error and ensuring a reproducible quality of the proposed treatments.

Moreover, they provide both the patient and the less experienced health professional with a reassuring, step-by-step care plan, devised by authoritative and/or more expert professionals or colleagues, which the practitioner can follow with confidence.

9.1 The Biomedical Diagnosis Underlying the Treatment Protocols

An attempt to identify the single cause of the patient's condition, the single biological element and the single discrete structural and tissual lesion underlying the clinical presentation has always been a distinctive feature of western medicine, one that differentiates it from theoretical approaches having other reference models and geographical origins such as traditional Chinese medicine.

On the basis of this "western" model, once the single compromised biological element has been identified, it is possible to target therapy specifically to that "lesioned" tissue, so as to resolve or best manage the patient's clinical condition.

The very *mission* of orthopaedic medicine has always been primarily to intervene on a compromised or lesioned tissue, by repairing it (Kumar and Jadhav 2014), reconstructing it or replacing it (Derar and Shahinpoor 2015).

Known as the *biomedical* model (Fig. 9.1), this model considers disease as a deviation from normal and identifies the patient with the illness affecting him. It has influenced orthopaedic medicine—and consequently rehabilitation medicine—for many years, leading to the proposal of different treatment protocols based almost exclusively on a biomedical diagnosis and targeting the clinical and biomechanical features that most characterise the disorder. An example of this is the active and passive approaches to limit cranial translation of the humeral head in subjects with subacromial impingement syndrome (Ludewig and Borstad 2003) (Table 9.1).

Treatment protocols have been extensively used in neuromusculoskeletal rehabilitation in both conservative and, above all, postoperative settings.

The biomedical model is particularly suited to patients recovering from surgery. In these patients, there is often a near-perfect correlation between the clinical presentation and the anatomical lesion (e.g. reconstruction of the medial collateral ligament of the elbow in athletes and subjects with acute lesion), which has a precise and relatively unmodifiable biological time frame for achieving adequate tissue repair and hence initiating rehabilitation.

This correlation is much less evident in conservative settings and in neuromusculoskeletal pain in general.

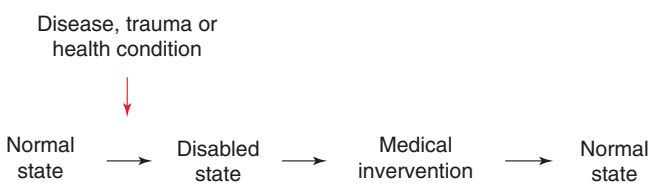


Fig. 9.1 The biomedical model

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Table 9.1 Therapeutic programme reported by Ludewig and Borstad (2003) for subjects with subacromial impingement syndrome

Exercise programme for subjects with subacromial impingement syndrome:
Mobility and stretching exercises: to be done daily. Five repetitions, 30 s per repetition for each exercise
Bilateral stretch of the pectoralis minor
Posterior-inferior capsule stretch: crossarm stretch
Scapular plane abduction: relaxation of the upper trapezius muscle
Strengthening exercises: to be performed three times a week. Three sets of ten repetitions each. Increase resistance and number of repetitions as tolerated
External rotation with elbow bent and close to the body to form a 90-degree angle: progress by increasing the humeral abduction
Serratus anterior muscle: scapular protraction in supine position

9.2 Neuromusculoskeletal Pain

The poor correlation between the radiological findings and the clinical presentation highlighted in the past 20 years and previously taken for granted has produced a lively debate in the scientific community and cast major doubts on the usefulness of the biomedical model in rehabilitation.

In particular, it has been found that subjects with neuromusculoskeletal pain often have similar radiological findings to asymptomatic subjects. In a population of 17 subjects affected by unilateral epicondylalgia, Mackay et al. (2003) assessed the findings on magnetic resonance imaging (MRI) of both elbows and found oedema of the common extensor tendon *even* in the healthy contralateral arm in no less than 6 subjects out of 17.

Moreover, although radiological findings are present in subjects with lateral elbow pain, their severity does not seem to correlate directly with the severity of the clinical presentation (Chourasia et al. 2013; Walton et al. 2011).

Similar observations have also been reported for other regions of the body.

In a population of *asymptomatic* subjects undergoing shoulder MRI, 30% of subjects aged 50 years and 50% of subjects aged over 60 years presented with rotator cuff lesions (Sher et al. 1995).

The clinical repercussions of these findings are extremely important.

If we exclude major lesions affecting the joints (Lustig et al. 2012) or extra-articular soft tissues (Paribelli et al. 2015), in which surgery is the only practicable approach, in cases presenting radiological and structural findings that have limited significance for the clinical presentation, any invasive intervention to repair these structures may be unnecessary and produce identical outcomes to a conservative approach.

In a population of over 400 surgical candidates with non-traumatic full-thickness rotator cuff tears, implementation of a conservative treatment allowed surgery to be avoided in 75% of cases, with significant clinical improvements also maintained at 2-year follow-up (Kuhn et al. 2013).

Faced with such observations and with an objective difficulty in identifying specific structures as definite sources of a given pain, the scientific community and especially rehabilitation specialists progressively abandoned the use of "pathoanatomical" terms in favour of a terminology which boldly uses the adjective "nonspecific" in describing some clinical-functional conditions, such as lumbar pain (National Collaborating Centre for Primary Care (UK) 2009) and cervical pain (McLean et al. 2010). In some cases, we have gone so far as to use terms predominantly based on the symptom and its anatomical distribution. For example, there is a growing use of terms like "anterior knee pain" (Werner 2014) and "epicondylalgia" (Waugh 2005) or plainly "lateral elbow pain" (Buchbinder et al. 2006) for clinical presentations often pathoanatomically related to patellofemoral disorders (Witvrouw et al. 2014; Foss et al. 2014) and tendinopathy of the extensor carpi muscles (Stasinopoulos and Johnson 2006), for which it is still unclear which structures are causing the pain.

Given that it is often impossible to identify a pathognomonic physical and tissual lesion, it is the constellation of presenting features that will characterise the clinical picture, in a concept that moves away from the pathoanatomical point of view and changes the very paradigm of neuromusculoskeletal rehabilitation.

Taking again patients with epicondylalgia as an example, we typically find a co-occurrence of clinical signs and symptoms, in particular pain, but also a reduction of range of motion (ROM) (Sölveborn and Olerud 1996), muscle weakness (Lucado et al. 2012) and changes of the soft tissues surrounding the painful region (Fernández-Carnero et al. 2007) associated with a diminished pain threshold which is not limited to merely the target segment, as demonstrated by evidence of an increased central sensitivity to pain (Fernández-Carnero et al. 2009).

Such situations can be found in musculoskeletal disorders in general, whether nonspecific low back pain (Delitto et al. 2012), nonspecific neck pain (Childs et al. 2008) or subacromial impingement syndrome (Diercks et al. 2014).

Some authors, applying a pathoanatomical view to the neuromusculoskeletal domain, have tried to identify the type of primary or most important "dysfunction" triggering the cascade of events leading to the patient's clinical presentation. By doing so, one can propose specific articular (Mulligan 2010; Hengeveld 2013), myofascial (Travell and Simons 1998; Stecco 2010) or motor control treatments capable of resolving the primary cause and hence the symptoms.

In a multifactorial context, if we analyse the situation critically, it is not surprising that single-modality treatments

targeting specific structures in subjects with epicondylalgia have yielded significant improvements in the short- to mid-term only, failing to produce any significant long-term benefits even compared to no treatment (Bisset et al. 2006).

More specifically, a programme of articular manipulations at wrist level proved more effective than a strengthening and stretching programme, after 6 weeks of treatment (Struijs et al. 2003).

Twelve weeks of myofascial treatment were more effective in reducing pain in subjects with epicondylalgia compared with a control group (sham ultrasound) at follow-up after 3 months (Ajimsha et al. 2012).

Moreover, in uncontrolled studies, radial nerve mobilisation techniques (Arumugam et al. 2014) and taping (Shamsoddini and Hollisaz 2013) resulted in less pain and improved grip strength in the immediate post-treatment period.

As stated, all these studies investigated the short- to mid-term outcomes, showing fairly good results.

Studies assessing the long-term efficacy of these treatments have produced less satisfactory outcomes. For example, a programme of eight sessions of joint mobilisation with movement according to Mulligan and exercise proved to be more effective than corticosteroid injections or no treatment at 6 weeks but not at 1-year follow-up, where all groups showed similar outcomes (Bisset et al. 2006).

In a multifactorial context like neuromusculoskeletal rehabilitation, where the features characterising the clinical picture are multiple and lacking a single, clearly identifiable cause to be taken as the "target", can a predetermined treatment protocol be considered the best possible care option for a specific clinical presentation, in a specific patient with those specific features?

Once a physiological, symmetrical and functional range of movement has been reached, does it make sense to continue with exercises for joint mobility recovery, or could this time be spent on other, as yet unresolved, limitations?

More importantly, can the same protocol be indicated for the same pathological condition in subjects with very different functional requirements? Will a professional rugby player with recurrent shoulder dislocation have the same functional requirements as a 50-year-old office worker suffering the effects of a first episode of dislocation? Can the same treatment protocol for "shoulder dislocation" be considered the best approach for both cases?

9.3 Subclassifications in Rehabilitation

Given the difficulty in clinically classifying patients with musculoskeletal disorders on the basis of the imaging findings, over the past 15 years, there has been a growing interest in clinical prediction rules (CPR).

CPR have been defined as "combinations of relevant clinical findings that have been statistically demonstrated to be meaningful predictors of a condition or outcome of interest, used to categorize a heterogeneous group of patients into subgroups based on a shared likelihood of the presence of that condition or outcome" Beattie and Nelson (2006).

A growing interest in this methodological tool emerged both in the diagnostic setting (Haskins et al. 2015a), to identify the most likely pathological conditions affecting a given subject, and in the therapeutic and prognostic setting (Haskins et al. 2015b), to predict the most effective treatments for a given patient on the basis of the initial assessment.

All in all, the attempt to identify a priori the most appropriate predetermined care plan on the basis of imaging findings or subclassifications based on a small number of factors seen at initial assessment has proved to be insufficient and as yet impossible to apply successfully in clinical practice. These observations should raise doubts about the common practice of proposing the same treatments to widely heterogeneous groups of subjects, especially in a multifactorial setting like neuromusculoskeletal rehabilitation.

An approach characterised by protocols to be accurately and closely followed would in fact require highly compelling evidence in favour of such practices that actually *demonstrates* the existence of objective gains to be had by reducing, albeit not completely limiting, the role of the health professional's clinical reasoning (Bandiera et al. 2003).

One example borrowed from the intensive care unit is the protocols for managing parenteral rTPA administration in subjects with acute stroke (Table 9.2) or fluid management in patients with hypovolemic shock in that these protocols are capable of improving particularly significant outcomes such as life expectancy and number of deaths (See et al. 2015; Lopez-Yunez et al. 2001).

Table 9.2 Violation of the recombinant tissue plasminogen activator (rTPA) administration protocol in subjects with acute stroke within the first 3 h reported by See et al. (2015)

The following were considered protocol violations:
• Administration of rTPA more than 3 h after the event
• Administration of rTPA >0.9 mg/kg or >90 mg
• International normalised ratio (INR) at baseline >1.7 or activated partial thromboplastin time
• Platelet count <100,000/mm^3
• Severe stroke or head trauma in the previous 3 months
• Major surgery in the previous 14 days
• Blood pressure at baseline >185/110 mm Hg
• Blood glucose <50 mg/dL or >400 mg/dL
• Epileptic crisis at the time of acute stroke
• Gastrointestinal or urinary haemorrhage in the previous 21 days
• Use of antiaggregants or anticoagulants during the 24 h following rTPA administration

We have seen how conservative rehabilitation has shown some limitations in this area. However, the same considerations often hold true for postsurgical patients as well.

9.4 Rehabilitation Protocols in Postsurgical Patients

As stated above, the loss of flexibility inherent in the application of treatment protocols needs to be justified by compelling evidence in their favour, with studies demonstrating a greater efficacy compared with alternative treatment plans.

An example is given by the rehabilitation protocols following anterior cruciate ligament reconstruction. Although for years there was a tendency to accelerate recovery times by applying the so-called accelerated protocols, high-quality studies have shown them to result in identical outcomes when compared to "non-accelerated" approaches at all significant follow-up points, from 6 months up to 2 years postoperatively (Kruse et al. 2012; Beynnon et al. 2011).

In any case, despite the ongoing evolution of surgical and rehabilitation techniques, we continue to have "low" rates of return to pre-lesional performance levels (Ardern et al. 2014) and unsatisfactory rates of reinjury (Laboute et al. 2010).

These data emphasise the need to better investigate the risk factors, underestimated until now, that may have a role in anterior cruciate ligament injury and reinjury, such as the potential role of altered lower limb biomechanics during weight-bearing (Myer et al. 2015).

That said, it should be underlined that even postsurgical rehabilitation requires the constant attention of an expert professional capable of assessing the possible risk factors that the rehabilitation pathway must address and tailoring rehabilitation to the specific requirements of the patient, who should be given a treatment plan defined in the immediate postoperative period, especially in the populations more at risk.

Even in this case, it is important to note how functional outcomes are placed at the centre of clinical practice in an evolution that has led to a progressive move away from the biomedical model in favour of a biopsychosocial model. In this latter model, the patient is no longer identified with his pathological condition or anatomical lesion but on the basis of how this affects his life and everyday functioning (Fig. 9.2).

"Functional" outcomes have entered common high-level clinical practice. Examples are validated questionnaires (patient-oriented outcome questionnaire) such as Disability of the Arm, Shoulder and Hand (DASH) in upper limb rehabilitation (Padua et al. 2003).

On the basis of these data, it is clearly impossible to use standardised and predetermined treatment protocols in musculoskeletal rehabilitation, as this is characterised by a high anatomical, functional and subjective variability of individual patients.

9.5 Protocols or Guidelines?

The rise and development of evidence-based medicine (EBM) has led to a growing production of scientific data on rehabilitation. In 1996, 5600 papers containing the word "rehabilitation" were indexed in PubMed, whereas by the year 2014, the number had risen to over 18,000.

In parallel, this rise in the number of published studies has made it increasingly difficult for health professionals to manage this huge amount of information, in terms of reading,

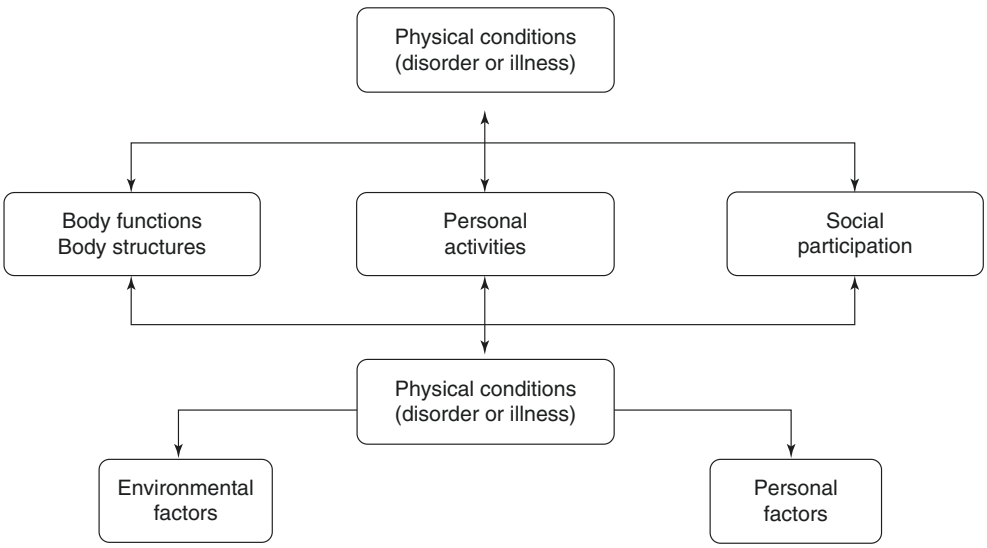


Fig. 9.2 The biopsychosocial model

assessing and incorporating it into their clinical practice. In an attempt to address these difficulties, clinical guidelines (GL) have been developed.

Guidelines are defined as "systematically developed recommendations for clinical behaviour to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances. These recommendations are intended to optimize patient care and are informed by a systematic review of evidence and an assessment of the benefits and harms of alternative care options" (Institute of Medicine (US) Committee on Standards for Developing Trustworthy Clinical Practice Guidelines. Clinical Practice Guidelines We Can Trust [Internet] et al. (2011)).

GL concentrate, in a single source, the basic elements of the effective management of specific clinical pictures through a careful selection and presentation of possibly high-quality scientific literature. Whenever this is not available, as, for example, in the case of rare or rarely studied diseases, recommendations for clinical management are usually derived from expert consensus.

Unlike protocols, GL contain a series of indications for clinical practice, from assessment to treatment to outcome measures, that are accessible to health professionals or service users—i.e., patients—and present the state of the art with reference to specific clinical pictures so as to enable informed therapeutic choices.

The formulated recommendations are, or should be, classified on the basis of the "strength" with which they are expressed. In the classification proposed by the GRADE Working Group (Atkins et al. 2004), the strength attributed to recommendations varies depending on the assessment of the "ratio between the benefits and harms, the quality of the evidence, translation of the evidence into practice and uncertainty about the baseline risk for the population" Herbert and Bozzolan (2014).

The increasing production of GL has led to a need to develop tools for assessing the quality of the GL themselves. One example is AGREE II (Appraisal of Guidelines, Research and Evaluation) (Brouwers et al. 2010a; Brouwers et al. 2010b), which proposes an appraisal based on 23 items divided into 6 domains: scope and purpose, stakeholder involvement, rigour of development, clarity of presentation, applicability and editorial independence.

The health professional has the crucial task of appraising the quality of the proposed recommendations, by verifying how and how closely the GL recommendations can be translated into clinical practice on the basis of their strength, characteristics of the patient being cared for, the professional's training and the organisational and environmental factors of the setting in which the professional operates.

There are many positive sides to these tools: a critical, accurate and accessible presentation of the state of the art for given clinical settings, mediated by the knowledge and clinical expertise of established professionals and distilled into recommendations based not only on supporting studies but also on their applicability and risk-benefit ratio.

Particularly for professionals lacking extensive experience or familiarity with the biomedical literature, GL can prove extremely useful for acquiring information and comparing one's own clinical practice with that suggested by authoritative sources.

It is no coincidence that adherence to high-quality GL has important clinical repercussions, such as significantly improved outcomes (Rutten et al. 2010) and reduced costs (Childs et al. 2015) in the physiotherapy treatment of subjects with low back pain.

Despite this, their application remains inadequate in the clinical practice of many professionals (Piccoliori et al. 2013).

Several studies have tried to identify the major barriers to the application of GL recommendations, in particular by means of surveys and questionnaires administered to health professionals.

Interestingly, these barriers are often accounted for by the different domains of the AGREE II guideline appraisal tool (Brouwers et al. 2010a; Brouwers et al. 2010b), mentioned above.

9.6 The Limitations of Guidelines

Inadequate adherence to GL seems to be mainly related to factors inherent in the patient or the organisation within which the professional works.

No doubt, the presence of standard settings is very useful for improving the internal validity of a study and minimising the factors confounding the results.

Internal validity refers to the methodological quality of the study. It is related to the methodological rigour followed during the study planning, conduction and analysis phases with the aim of minimising confounding factors, known as biases, and systematic errors (GIMBE - EBM 2015).

Good internal validity is crucial for determining the reliability of study results, but alone it is not sufficient to allow the professional to arrive at a clinical decision. One also needs to consider clinical relevance, i.e. an estimate of the effects produced by the intervention, consistency or the reproducibility of results by other studies and external validity, defined as the extent to which the results can be applied to the single patient (GIMBE - EBM 2015).

It should also be noted that the publication of a GL does not necessarily imply that it is of good quality nor that all the aspects described above have been considered during its development.

In particular, it is often remarked that there are substantial differences between daily practice settings and the proposed clinical scenarios.

Furthermore, possible comorbidities and the use of systemic pharmacological treatments, increasingly frequent with increasing mean age and ageing of the population, or the patient's actual compliance to a given treatment can all heavily influence treatment decisions (Lugtenberg et al. 2009).

Moreover, many GL fail to take into account the time, resource and facility requirements (Lugtenberg et al. 2009; Cabana et al. 1999) of the proposed treatments and the cost of implementing them, in particular as regards effect size, i.e. the magnitude of the difference in results between the experimental and control group following the proposed intervention; all this correlated to the cost-benefit ratio.

A highly expensive treatment that produces only marginally better outcomes compared with a much less costly standard would risk limiting the patient's ability to benefit from the best possible treatments having the same cost for himself and for the health system.

Organisational, environmental, economic, professional aspects should be incorporated into GL, possibly by reporting specific recommendations for specific work settings so as to make the GL more usable by health professionals.

At the same time, the possibility of implementing the GL recommendations is often limited by the professional's lack of specific competences.

An example is the indication of therapeutic exercises, which have shown to be extremely important in almost all musculoskeletal clinical settings.

But what exercises? With what intensity, duration and frequency? Aiming to improve resistance, strength or power? (Van Cant et al. 2014). Or is the specificity of the exercise not so important? Or if it is important, is it stated in the recommendations?

Moreover, in appraising the clinical utility of some GL, it will be important to check what professionals developed them and who the GL are written for. GL produced by an association of physiotherapists, and written for physiotherapists (Delitto et al. 2012), could have limited relevance to a general practitioner and vice versa.

Considering the multifactorial and multidisciplinary nature of the management of many musculoskeletal disorders, the proposed solution—included into the above-mentioned AGREE II tool—is to create multidisciplinary teams bringing together the knowledge and collaboration of different health professions and providing a picture that is as comprehensive as possible. For example, the Dutch GL for rehabilitation for subacromial impingement syndrome (Diercks et al. 2014) were jointly drafted by the Dutch societies of orthopaedics, physiotherapy, family medicine, rehabilitation medicine, occupational medicine and radiology. Similarly, the GL for recovery from loss of elbow motion in children produced by the Cincinnati Children's Hospital Medical Center (Kovacs et al. 2007) were developed by physiotherapists, occupational therapists, orthopaedic surgeons and experts in research methodology.

Methodological aspects should also be taken into account when producing or assessing GL. An accurate description of the methods used to search the literature and develop the recommendations will allow us to verify whether this was done correctly, to evaluate the role of possible errors—also potentially facilitated by conflicts of interest—and to fully understand whether the recommendations refer to clinical settings of interest for our practice. Will the treatments proposed for a general population with elbow pain be able to restore the best possible function in a professional athlete with recurring chronic pain after a traumatic event? Clearly, it depends. And it is precisely the clarity with which the data are presented that will allow the professional to assess how to combine them with his own clinical expertise within a care plan.

A further aspect not to be underestimated is the frequently raised objections as to the obsolescence of the treatments reported in the recommendations, which are sometimes not regularly reviewed and in general do not contain references to the most recent scientific research.

This aspect deserves further discussion: as stated, the role of GL is to present the foundations for an accurate, ethical and generally reasonable clinical practice. For this reason, inclusion of specific interventions in the recommendations must be supported by high-quality scientific studies owing to the risk of including promising but costly therapies which, on closer analysis and with more rigorous studies, might subsequently show disappointing results. All this is absolutely correct and appropriate.

However, if we consider the time elapsing between carrying out a primary study; publishing the results in an indexed journal, including the results in a high-quality systematic review; and subsequently using this systematic review as a source for a given recommendation, it is clear that even many years can pass.

9.7 The Limitations of Health Professionals

If the critical points described above may cast doubt on the use of this type of reference in clinical practice, the behaviour of health professionals cannot be said to be completely impeccable.

Knowledge of the content of guidelines by health professionals is inadequate (Lugtenberg et al. 2009), whereas their application in clinical practice appears to be heavily influenced by the professional's working habits and the patient's expectations and demands (Lugtenberg et al. 2009; Chenot et al. 2008; Lugtenberg et al. 2011).

Poor knowledge of the scientific literature and conscious reliance on customary clinical practices based exclusively on their repetition therefore seem to be determining factors in the failure to use these recommendations.

Educational sessions addressing the implementation of GL in clinical practice appear to be effective in modifying GL adherence (van Dulmen et al. 2014; Peter et al. 2013), which is correlated, as stated, with clinical improvements and cost reductions (Rutten et al. 2010).

Often, in fact, strong recommendations that are inexpensive and easy to apply are not even proposed to patients (Ylinen et al. 2013). Although in some cases this may depend on the single subject's clinical context, when it occurs in a large number of patients, one may suspect that it is the health professional who is proposing an obsolete and expensive practice with unjustified clinical risks.

9.8 What Should Be Done

Implementation of the information contained in the guidelines is highly desirable, as is a greater attention to evidence-based clinical practice.

It is no coincidence that the barriers that seem to hinder GL adherence by many professionals are the same as those reported to hinder evidence-based practice (Mota da Silva et al. 2015).

For this reason, particularly at a time when the economic resources allowing an effective and sustainable health system are dramatically decreasing, behaviours dictated by poor knowledge of evidence-based medicine are no longer acceptable. All the more so if they form a part of repetitive clinical customs based on treatment protocols.

Scientific evidence can be integrated with one's own skills and clinical experience, as well as with the patient's preferences, so as to provide the best possible rehabilitation care.

Citing David Sackett, creator and founder of evidence-based medicine:

"Good doctors use both individual clinical expertise and the best available external evidence, and neither alone is enough. Without clinical expertise, practice risks becoming tyrannised by evidence, for even excellent external evidence may be inapplicable to or inappropriate for an individual patient. Without current best evidence, practice risks becoming rapidly out of date, to the detriment of patients. (…).

External clinical evidence can inform, but can never replace, individual clinical expertise, and it is this expertise that decides whether the external evidence applies to the individual patient at all and, if so, how it should be integrated into a clinical decision" Sackett et al. (1996).

Conclusion

In summary, the literature data and evidence-based guidelines themselves should, despite the defects that often characterise them, form the basis on which to build our daily clinical reasoning and practice. To this end, it would be extremely useful for their study to be included in the physiotherapy degree programmes so as to adequately educate students on that pillar of best practice consisting of the best available literature.

However, rehabilitation is very often relegated to an automatic repetition of customary practices whereby identical treatment protocols are used for widely diverse patients, despite the possibility that they may be anachronistic or affected by subjective biases.

So, are guidelines useful in rehabilitation practice? Definitely! Are they sufficient? Definitely not.

As seen above, real-world, daily clinical practice settings rarely match the settings and populations considered by high-quality randomised controlled trials. Therefore, it is up to the professional to be able to recognise publications of high methodological quality, interpret their recommendations and incorporate them into clinical practice alongside the clinical experience and competences developed over years of practice, identifying "which" manual therapy technique to use and "which" exercise with "what type and how much" load and "what" frequency should be proposed to "that" specific patient.

All this should be adapted to the experience of the person we are caring for, his or her daily context, preferences and functional requirements, which should be put at the centre of the treatment plan.

For these reasons, any clinical practice based on treatment protocols cannot be considered to be of a high level. Standardised treatment plans may work in a good proportion of patients given the multifactorial nature of the clinical settings we are faced with. However, we need to be aware that a clinical improvement may be due to a series of nonspecific physiological mechanisms, the placebo effect which can produce major biological changes (Finniss et al. 2010), the patient's expectations (Dima et al. 2013) and the natural course of the disease (Gurcay et al. 2009).

In view of these limitations, a clinical practice that critically scrutinises itself can only improve outcomes and the functional recovery of our patients and the whole health system we operate in.

So are protocols useful in rehabilitation care? As stated initially, they undoubtedly have several advantages, although these do not seem to be related to the idea of providing the best possible health care.

Taking charge of the patient's care should be a multidisciplinary and personalised process that succeeds in uniting the positive aspects of complementary approaches, such as the pathoanatomical approach typical of orthopaedic surgeons and the functional and biopsychosocial approach which is (should be) typical of rehabilitation professionals. This, in particular, applies to those patients presenting with polymorphous clinical features, for whom scientific evidence can serve as a basis, while what really makes a difference is the health professionals' knowledge and competence.

9.9 Author's Opinion

Knowledge of clinical variability with which skeletal muscle diseases may arise and the experience gradually gained in the field in these years of experience provided us the means to obtain common behaviour guidelines that can be helpful in the different situations we face.

We are unfortunately aware to the lack of rehabilitation guidelines and that standardised protocols in literature are often too rigid and so inadequate.

The intent of this book, therefore, is to transmit to the reader the behaviour method of an "expert team on elbow". This method starts from the knowledge of the basic pathology and of the different treatment options today at our disposal to create a personalised and effective rehabilitation programmes for that patient.

We hope in this way to be able to provide some useful tips and strategies of conduct for those who wish to approach the elbow and its pathology.

For an object lesson of what we said, we propose a real example of how the approaches to the same disease can be different if carried out without taking into account the clinical experience.

Patient of the following example has been made diagnosis of right epicondylitis (patient is right dominant).

In this chart, we propose you can read what patient has actually done to heal on the left side and our modes of behaviour (described in the book) on the right side.

Programme really done by the patient	Book described programme accordingly to the lines of conduct that we believe necessary for this pathology
Orthopaedic and ultrasound diagnosis	Orthopaedic and ultrasound diagnosis
Number 4 cortisone injections	Manual/instrumental and eventually osteopathic treatment Brace use
After injection failure, open surgery for epicondylitis was immediately proposed to the patient	When pain decreases: strengthening exercises in eccentric contraction and specific stretching exercises. Continue manual therapy if necessary
Surgery complicated by postoperative wound infection, arm/forearm oedema, important increase of pain. It ensued antibiotic therapy, functional rest, prohibition of carrying out any rehabilitation treatment	If pain persists, PRP treatment is proposed going on with home exercises or exercises in rehabilitation pool if possible
	If the pain had to be still intense, we propose targeted shock waves
NB: patient not only has to solve his problem yet but also manage its complications. Problem now is double. Need of orthopaedic, physiatric and infectivological repeated checks	If the pain was to be still intense: surgery
After infection solving, weeks after surgery, beginning of passive and active ROM recovery, drainage therapy, analgesic drugs and therapies	
As ROM becomes satisfactory: active exercises	
Upper arm recovery completed at the end but is requested about 6 months of time, many therapies and multi-specialists medical visits Work absence just as long	

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Part II

Surgical and Conservative Techniques

Elbow Dislocation and Instability Classification

10

Alessandro Marinelli, Enrico Guerra, Marco Cavallo, Michelle Dos Santos Flöter, and Roberto Rotini

10.1 Introduction

The elbow is a stable, congruent joint. Nevertheless, instability of this joint is not a rare event, especially after injury. It has been estimated that the rate of simple elbow dislocations is about five to seven cases per 100,000 patients per year (Josefsson & Nilsson 1986; Yang et al. 2011; Stoneback et al. 2012; Hindle et al. 2013). In addition there are fracture-dislocations, such as the terrible triad injuries, and trans-olecranon fractures, but the rate of these is hard to estimate from the literature.

In the past, dislocations, combined or not with joint fractures, were treated by reducing the joint and immobilizing it in a cast for a long time. Thus, the healing of instability—a painful and disabling condition—was attempted by creating a condition of stiffness, which is usually not painful and more acceptable clinically. The resulting arthritic degeneration from cases that healed with partial joint incongruity led to a partially stiff elbow, which was, however, stable and pain-free. Transforming traumatic instability into a stiff elbow was for years deemed to be the lesser evil and accepted by patients and physicians alike as the natural outcome of this injury.

Since the 1980s, patient demands and surgeons' ambitions to achieve better results have prompted studies about anatomy and biomechanics of the elbow (Morrey et al. 1979; Morrey & An 1983, 1985; Morrey et al. 1991). The value of these studies is to have identified the anatomical structures responsible for elbow stability (Fig. 10.1):

– The primary stabilizers are the ulnohumeral joint, the anterior bundle of the medial collateral ligament (aMCL), and the lateral ulnar collateral ligament (LuCL).
– The secondary stabilizers are the radial head, the joint capsule, the common flexor-pronator tendon (CFPO), and the common extensor tendon (CEO).

Based on improved biomechanical knowledge and clinical experience, at the end of the 1990s, Morrey (Morrey 1997) coined the phrase "complex elbow instability." Since then, this term has enabled us to distinguish two different clinical conditions: dislocation due exclusively to injury of the soft tissues—already known as "simple elbow dislocation (Josefsson & Nilsson 1986; Mehlhoff et al. 1988)—and dislocation combined with radial head fracture and/or coronoid process, known as complex elbow dislocation (Morrey 1997; Hildebrand et al. 1999).

In the "simple" forms, as already underlined, the damaged stabilizers are only soft tissues: collateral ligaments, capsule, and sometimes extensor and flexor muscles. However, cases with small articular fractures that do not compromise stability are also included in the "simple" forms (O'Driscoll 2000a). These forms are nearly always treated conservatively and generally have a good prognosis.

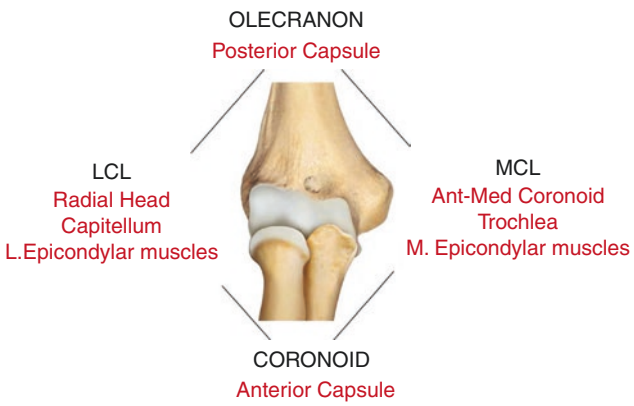


Fig. 10.1 Elbow stabilizers: the fortress concept (O'Driscoll et al. 2001a). The three primary stabilizers of the elbow include (1) the ulnohumeral joint (olecranon and coronoid), (2) the anterior bundle of the medial collateral ligament (MCL), and (3) the lateral ulnar collateral ligament (LCL). The secondary stabilizers are marked in *red*

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Conversely, the "complex" forms, previously known as fracture-dislocations, are a combination of soft tissue injury (capsule and ligaments) and bone lesions (mainly the radial head, coronoid, and olecranon). These forms generally require surgical treatment and have a poorer prognosis compared with that of the simple forms.

Although the classification of "simple" and "complex" is very useful to determine acute and traumatic lesions, it does not cover rarer chronic forms, which are also mostly the result of acute traumas, but sometimes have different etiologies, such as microtraumas, rheumatic diseases, neurological disorders, and sequelae of infection or congenital diseases.

In the absence of a good classification and a defined terminology in recent years, we have been faced with some clinical cases of instability that we have not been able to define in a univocal way using a terminology shared within our own ward or with other colleagues.

The trouble with designing a simple straightforward classification for elbow instability, as highlighted by O'Driscoll (O'Driscoll 2000b), is that there is such a wide variety of lesions according to etiology, stabilizers involved, timing, severity, and type of treatment.

With this in mind, however, in recent years, we have been looking for a classification system and a common language to organize the different types of elbow instability not only that of post-traumatic origin.

In this chapter we propose our classification for elbow instability, in order to improve our understanding of the disease, reduce misunderstanding of diagnosis, and improve comparison between experience and case series.

10.2 Elbow Instability Classification

The concepts of instability and dislocation are apparently simple and intuitive, but there are some clinical conditions especially in the elbow that can be confusing. A healthy elbow is reduced, i.e., its joint surfaces are well aligned and stable; that is to say that joint alignment is maintained throughout its entire range of movement regardless of the stresses it undergoes.

Dislocation/subluxation can be defined as a static condition characterized by a loss of normal joint relationships and instability as a dynamic condition where, due to movement or mechanical stress, a reduced joint can lose its congruency (dislocation/subluxation).

Based on these premises, all forms of elbow instability/dislocation can be grouped into three main types (Fig. 10.2): not reduced unstable, reduced unstable, and not reduced not reducible.

The "not reduced-unstable" type includes simple elbow dislocation (SED) not yet reduced and acute complex elbow instability, the "reduced-unstable" type includes the forms of temporary instability after a recent reduction of an SED and chronic recurrent instability, and the "not reduced-not reducible" type includes SED not reducible and persistent chronic dislocation (Fig. 10.3).

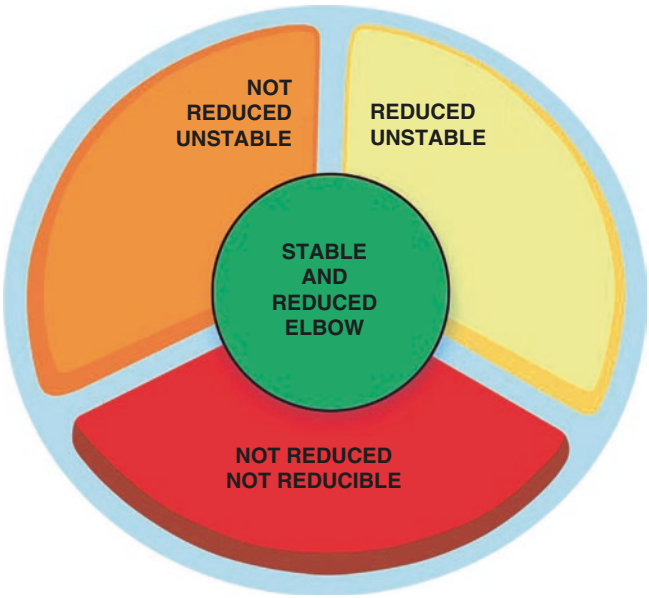


Fig. 10.2 The three patterns of elbow instability: not reduced unstable, reduced unstable, and not reduced not reducible

For a better characterization of elbow instability, there are other parameters, besides reduction and stability, which should be taken into consideration. These are:

1. The stabilizers involved: simple and complex forms
2. Timing: acute, chronic recurrent, and chronic persistent
3. The extent of dislocation: subluxation and dislocation
4. Etiology (trauma, microtrauma, congenital, inflammatory disease, neurological disease, sequelae of infection)
5. The joints involved: ulnohumeral, humero-radial, and proximal radioulnar
6. Mechanism of dislocation/instability: posterolateral rotatory instability (PLRI), posteromedial rotatory instability (PMRI), valgus, varus, and direct posterior

Considering the first two parameters, stabilizers involved (type A, avulsion of soft tissues; or type B, bone fractures + soft tissues lesion) and timing, we can divide elbow instability into six main groups: (1) A acute, (2) A recurrent, (3) A persistent, (4) B acute, (5) B recurrent, and (6) B persistent. Within each group we can divide instability according to etiology (Table 10.1), extent of dislocation (full dislocation or subluxation) and joints involved.

For instability of traumatic or microtraumatic origin, the lesion mechanism can be described. The most common mechanisms are posterolateral rotatory, posteromedial rotatory, direct posterior, varus stress, and valgus stress.

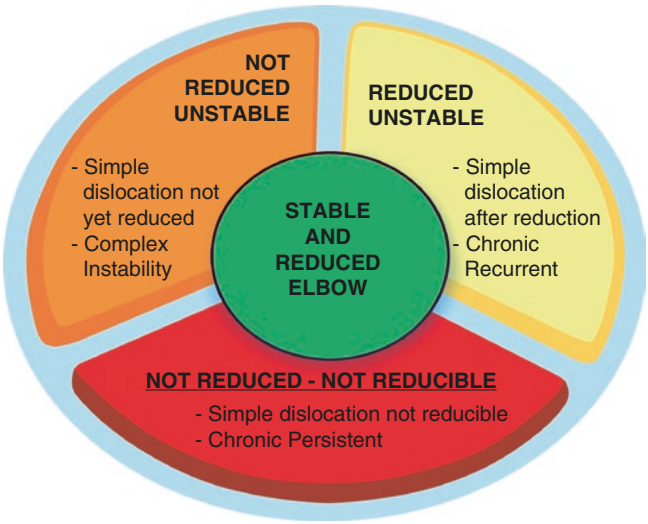


Fig. 10.3 Classification of elbow instability based on clinical and radiological examination

The orange sections in Table 10.1 show not reduced-unstable elbows; the yellow sections show reduced-unstable elbows; and the red sections show not reduced-not reducible elbows.

The subdivision into simple and complex forms as proposed by Morrey is kept in this classification, but it is also extended to chronic forms. Chronic instability is divided into two forms:

– "Recurrent," which are dynamic forms, where the elbow is basically reduced, but it dislocates or subluxates when subjected to physiological stresses
– "Persistent," which are static forms, where the elbow has been dislocated or subluxated for more than 2/3 weeks and can only be reduced surgically

Elbows with acute instability, which are by far the most common types, are only caused by trauma. More than 90% of elbows with chronic instability are post-traumatic and are usually the result of a lack of healing of an acute lesion, usually for

Table 10.1 All-inclusive classification of elbow instability

ELBOW INSTABILITY CLASSIFICATION SICSeG	ACUTE	CHRONIC RECURRENT (dynamic dislocation)	CHRONIC PERSISTENT (static dislocation)
SOFT TISSUE TYPE A	- TRAUMA *Simple Dislocation* POSTERIOR (PLRI, AXIAL VALGUS)	- Post Traumatic - Over-use - Congenital Hyperlaxity - Rheumatic Disease (I-II)	- Post Traumatic - Neglected or Failed treatment
SOFT TISSUE + BONE TYPE B	- TRAUMA *Articular Fractures of:* RADIAL HEAD, CORONOID, OLECRANON, DISTAL HUMERUS + LCL /CLM	- Post Traumatic LCL lengthening for cubitus varus or deficit of coronoid - Iatrogenic Radial Head excission - Rheumatic Disease (III-IV) - Congenital Dysplasia	- Post Traumatic - Neglected or Failed treatment

a failure of the attempted treatments. More rarely the causes can be due to a failure to recognize or to the decision not to treat the dislocation; these forms are defined as neglected. Besides traumatic forms, other causes of chronic instability, recurrent and persistent, are repeated stress, typical of professional overhead throwing athletes, the sequelae of pediatric trauma (cubitus varus, deficit of coronoid), rare cases due to congenital anomalies (hyperlaxity or congenital deformity), sequelae of infection or rheumatic diseases, which lead to a progressive destruction of the joints, or neurological diseases (spasticity).

10.2.1 Type 1: Acute Forms (Soft Tissue)

This group of lesions includes simple elbow dislocation which occurs as a result of acute trauma. Simple dislocations can be divided into posterior, anterior, and divergent (Fig. 10.4).

10.2.1.1 Posterior Direction

The direction of a simple elbow dislocation is nearly always posterior and usually occurs by falling on the hand with the elbow extended. The most common dislocation mechanism is the PLRI (O'Driscoll et al. 1991) where the axial force combined with valgus and supination stress produces a circular lesion of the stabilizers, which starts in the lateral collateral ligament and progressively involves the anterior and posterior capsule, until it involves the medial collateral ligament. The lesion mechanism occurs through three successive stages (O'Driscoll et al. 2001b) (Fig. 10.5):

Stage 1. The joint is subluxated: the trauma causes the lesion of the lateral ulnar collateral ligament.

Stage 2. The joint is dislocated with the trochlea perched on the coronoid process: the lesion of the anterior and posterior capsule adds to the further lateral collateral ligament injury.

Stage 3. The joint is completely dislocated: the previous ligament and capsular lesions are combined sequentially with injury of the posterior portion of the medial collateral ligament (stage 3A), the entire medial collateral ligament (3B), and the tendon insertions of the medial and lateral epicondyle, resulting in a complete stripping of all soft tissues from the distal humerus ligaments, capsule, and tendons (3C) (O'Driscoll et al. 2001b).

More recently, several authors have postulated that in some cases the posterior dislocation mechanism might occur in the opposite direction, from medial to lateral, by axial compression and valgus stress (Søjbjerg et al. 1989; Josefsson et al. 1987; Schreiber et al. 2013, 2014; Rhyou & Kim 2012).

Independently from the mechanism, the treatment of a simple elbow dislocation is the closed reduction, usually sedation-assisted. After reduction, an early protected motion can be generally allowed after a few days, and a clinical and/or radiographic follow-up is recommended to rule out the possible cases of re-dislocation. The surgical treatment is usually indicated only in the following two clinical settings:

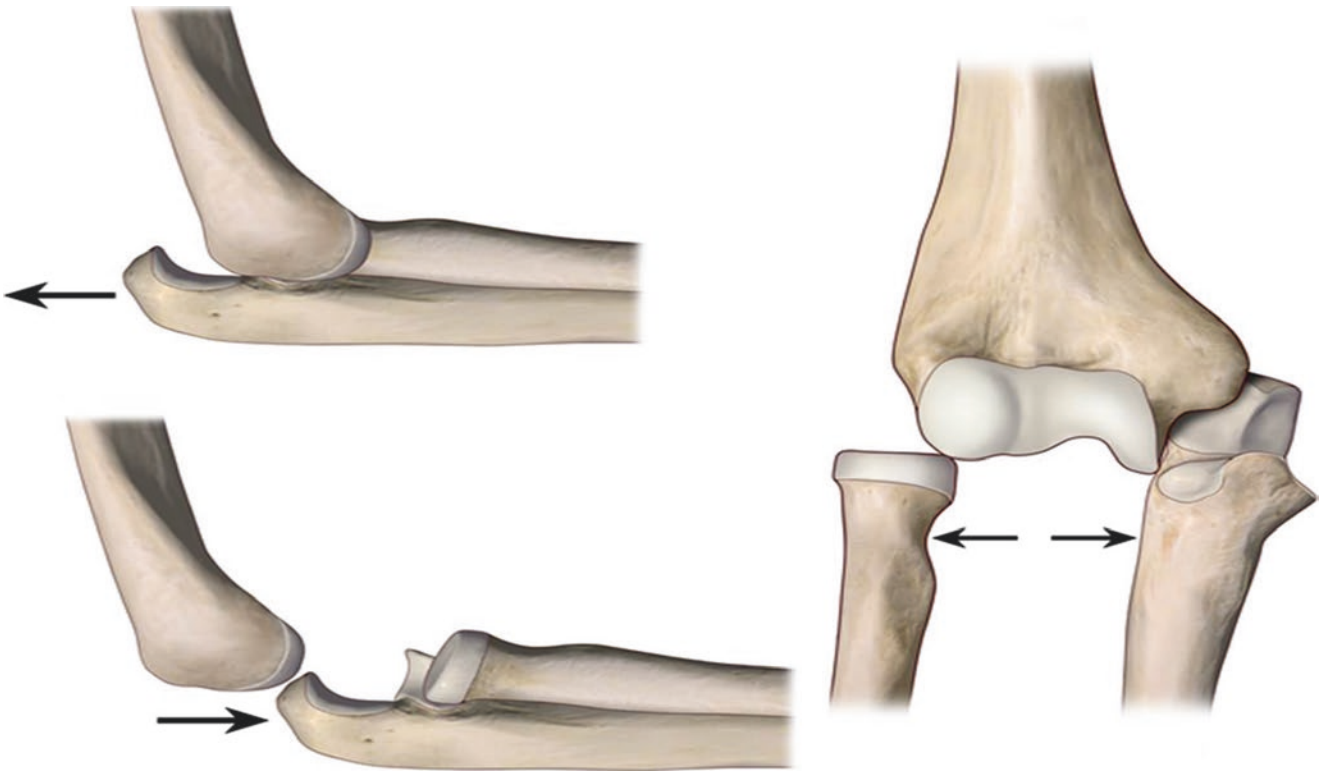


Fig. 10.4 Types of simple elbow dislocation: posterior, anterior, and divergent

– An irreducible dislocation, generally caused by soft tissues or osteochondral fragment entrapment.
– A gross instability with impossibility to maintain the ulnohumeral congruency under 90° of flexion. This form is caused by a complete avulsion of the soft tissue from the distal humerus (Stage IIIC).

10.2.1.2 Anterior or Divergent Direction

Anterior or divergent simple elbow dislocations are very rare, above all, in the adult and are generally combined with severe soft tissue lesions. In these cases the reduction can be difficult, and it should be performed in the operating room with an adequate muscle relaxation, appropriate analgesia, and under fluoroscopic guidance.

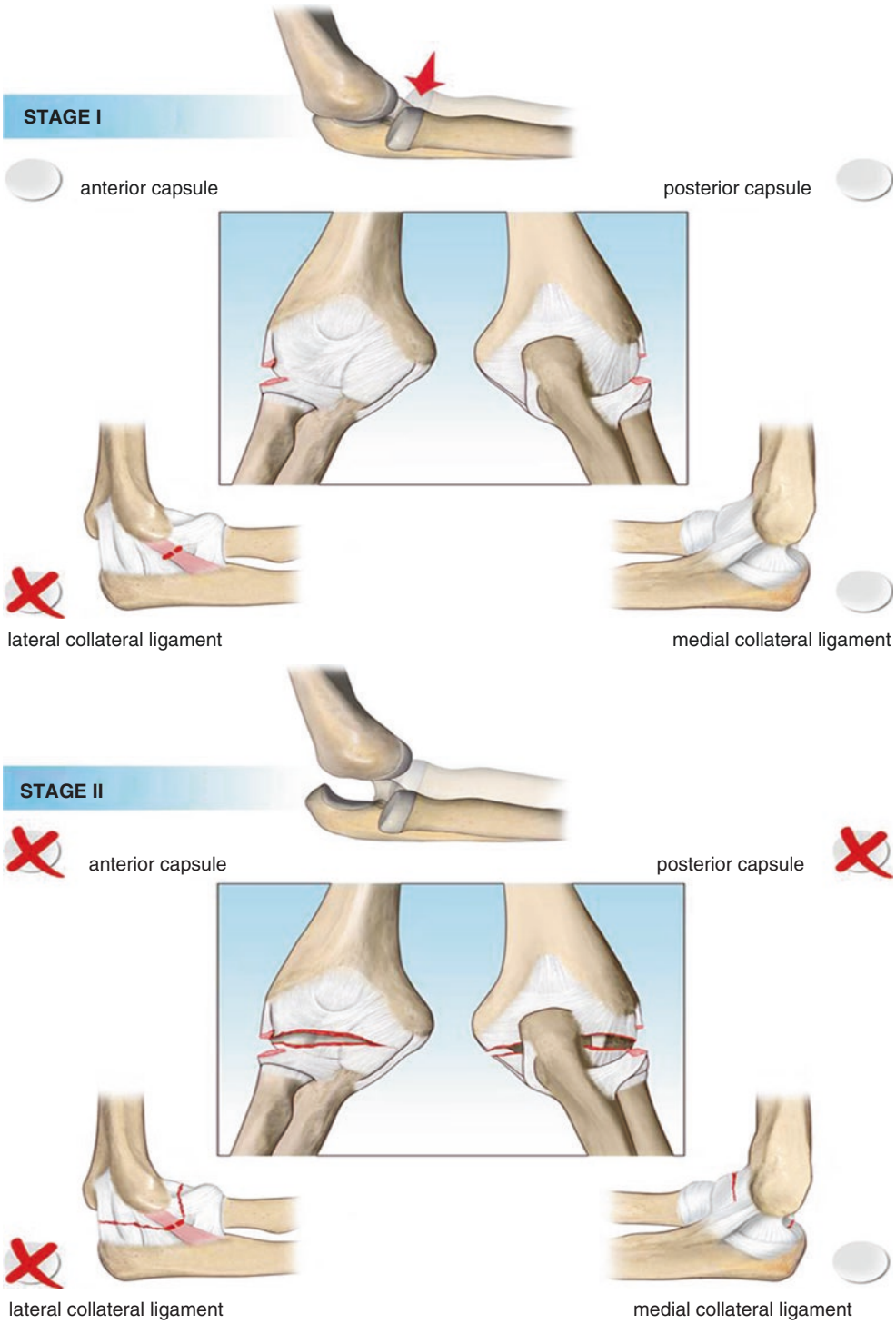


Fig. 10.5 Simple posterior dislocations caused by a posterolateral rotatory mechanism (PLRI). The mechanism of injury determines a three-stage soft tissue disruption that starts from the lateral side and progresses to the medial side. Stage 1: LUCL lesion. Stage 2: anterior and posterior capsule lesion. Stage 3: lesion of the medial collateral ligament

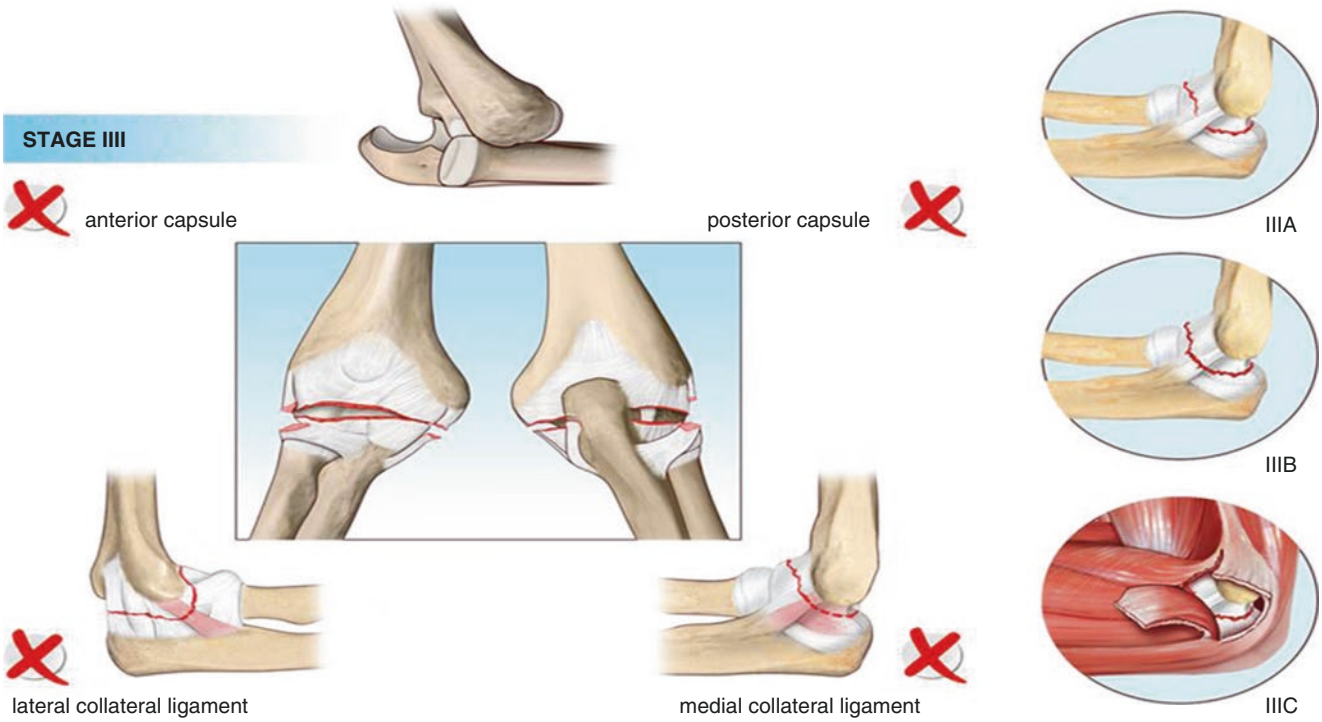


Fig. 10.5 (continued)

10.2.2 Acute Forms: Bone + Soft Tissue

This group includes a heterogeneous group of lesions characterized by the association of injury of bone and soft tissue stabilizers.

Inside this large group of disorders are included the so-called complex elbow instabilities (CEI), which are fracture-dislocations of the elbow, characterized by the dislocation of the ulnohumeral joint as a result of a fracture of a bone stabilizer (usually the radial head and/or coronoid or olecranon process) combined with injury of a ligamentous stabilizer (MCL and/or LCL). The types of lesions included in CEI are:

1. Trans-olecranon fracture-dislocation: these occur by an axial compression mechanism. Depending on the relative movement of the radial head with respect to the humerus, they are divided into anterior and posterior.
2. Terrible triad: this lesion is characterized by dislocation or subluxation of the elbow which occurs by fracture of the radial head, coronoid process, and lateral collateral ligament. The most common mechanism by which the terrible triad occurs is the PLRI.
3. Fracture of the anteromedial portion of the coronoid process and LCL injury: this type of lesion can be sometimes associated with radial head fracture and occurs by the PMRI mechanism. It usually causes a ulnohumeral incongruity rather than a complete dislocation.

Although not originally included in the complex elbow instability group (Hildebrand et al. 1999; Morrey & O'Driscoll 2000), there are some types of lesion combinations which, according to some authors, may be included in the complex instabilities—due to their anatomopathological features (contemporary bone and ligament lesions), similarity in treatment strategy, and prognosis. Although the debate is open, in this classification, which was designed for didactic purposes, we include the following fractures as complex elbow instability:

- Some forms of capitellar-trochlear fracture that, combined with capsuloligamentous lesions, show a pattern of instability with prognosis and treatment characteristics so close to other complex elbow instability forms that some authors include them in this group of lesions
- Even some isolated fractures of the coronoid process combined with instability, for example, with ulnohumeral joint incongruity as seen on CT, according to some authors, can be included in the complex elbow instability group.

Other patterns of instability presenting association of injury of bone and soft tissue stabilizers, but not causing a dislocation of the ulnohumeral joint, are not considered CEI. Some possible examples are radial head fracture combined with lateral or medial collateral ligament, radial head fracture combined with interosseous membrane injury (Essex-Lopresti), or Monteggia fracture.

10.2.3 Recurrent Forms: Soft Tissue

This group includes forms with different etiologies:

10.2.3.1 Post-Traumatic Forms

Most forms of recurrent instability occur by the PLRI mechanism (O'Driscoll 2000b) as the sequela of failed healing of the lateral collateral ligament injury. Valgus instability due to failure to heal of the medial collateral ligament is rarer, but possible.

10.2.3.2 Overuse

The most common cause of instability due to overuse involving only the soft tissues is damage to the medial collateral ligament produced by progressive stretching (chronic attenuation) which occurs in professional athletes who play overhead sport, especially baseball.

Rare cases of varus instability due to overuse of the lateral collateral ligament in people walking with crutches are also described in the literature (O'Driscoll 2000b).

Some rare congenital forms, for example, the Ehlers-Danlos syndrome (Cole et al. 2000), may cause recurrent elbow instability due to the laxity of the capsulo-ligamentous structures and symptomatic subluxation in hyperextension.

10.2.3.3 Rheumatic Disease

Initial forms of rheumatoid arthritis, mainly involving the soft tissues (grades 1–2 of Larsen classification) (Larsen et al. 1977), might produce recurrent instability.

10.2.4 Recurrent Forms: Soft Tissue + Bone

This group includes clinical cases of recurrent instability where the bone deficit is combined with a ligamentous lesion.

These include:

- Iatrogenic cases: excision of the radial head combined with not repaired and not healed injuries of the collateral ligaments. In these cases instability occurs during physiological movement or stress.
- Rheumatic disease: final stages (grades 3–4 of Larsen classification) (Larsen et al. 1977), with elbow centered at rest, but unstable during physiological stress or movement.
- *Post-traumatic deformity* (more common) or *congenital deformity*. The bone deformity of the medial condyle (cubitus varus (O'Driscoll et al. 2001c) or coronoid process (Okazaki et al. 2007; Bellato et al. 2016)) over time causes abnormal varus stresses, producing a chronic attenuation of the lateral collateral ligament, and a progressive instability that occurs by the PLRI mechanism. In these forms it is important to recognize and treat the bone injury: repairing or reconstructing only the lateral collateral ligament would result in failure if not combined with treatment of the bone injury, which consists of valgus osteotomy for cubitus varus and bone graft for the coronoid deficit (Okazaki et al. 2007; Bellato et al. 2016).

10.2.5 Persistent Soft Tissue

Persistent soft tissue dislocations are relatively rare and include the missed diagnosis (or neglected forms) that is rare in developed countries and the forms caused by an inappropriate or failed treatment. In the failed treatment forms, where a re-dislocation occurs in a plaster cast or in a brace, the diagnosis can be delayed if a strict clinical and/or radiographic follow-up is not performed. When the joint has been dislocated for longer than 2–3 weeks, it can no longer be reduced conservatively. Treatment requires extended arthrolysis and repair or reconstruction of the collateral ligaments combined or not with the use of an external fixator. The reconstruction of the ligaments with autologous or homologous grafts is usually required after 3 months or more of dislocation.

10.2.6 Persistent Soft Tissue + Bone

Persistent soft tissue + bone forms are the most difficult clinical cases to solve. They are a real challenge even for the most skilled elbow surgeon. We can also divide this group into "neglected forms" (very rare in developed countries) and "failed treatment" forms, which are instead not so uncommon. The most common type found in our experience is the terrible triad not treated or treated by simply removing the radial head, without fixing the coronoid process or repairing the lateral collateral ligament. Other not uncommon cases are caused by the failure to repair a large fragment of the coronoid process in trans-olecranon fractures. These forms can also include the sequelae of the Essex-Lopresti fracture-dislocations.

In this type of injury, stiffness and instability co-exist and treating one may risk aggravating the other. Surgery of these lesions consists of extensive arthrolysis, replacing the radial head bone defect with a prosthesis, reconstructing the coronoid process with grafts, reconstructing the collateral ligaments (generally with grafts), and possibly stabilizing with an external fixator. In some cases, osteotomy of the radial neck and proximal ulna has been described (Bellato et al. 2016) to address appropriately the joint surfaces. In case of severe and debilitating joint damage, a total elbow procedure can be considered a surgical option, especially in old and low-demand patients.

10.3 Discussion and Conclusion

Elbow instability is a complex and fascinating topic, which has been better understood over the last 25 years, since the role of the stabilizers and their possible interaction have been better understood.

Elbow instability encompasses numerous clinical types. The most common forms observed are of post-traumatic origin, but instability can be caused in other ways (microtrauma, rheumatic disease, neurological injury, congenital causes, and infection). A classification that is both exhaustive and practical is difficult to achieve precisely because there are numerous different parameters involved. However, increased knowledge and experience about elbow diseases has shown that instability can be chronic, recurrent, or persistent, even of a non-post-traumatic origin, and a precise definition and univocal terminology are lacking. This lack means that until now it has been hard to define with certainty and in a universally accepted way some cases of instability. Therefore, we tried to find a classification to help avoid diagnostic misunderstandings and favor comparison among case series. There are still surely several controversial points that will have to be settled in the future. These include whether complex elbow instability comprehends only the forms originally described by Morrey or if they can be extended to other types of lesion. Can Monteggia and Essex-Lopresti fractures be considered as elbow instabilities with combined forearm lesions, or precisely because they involve the forearm and wrist should they be included in another classification system? Is the axial valgus really a possible mechanism for simple dislocation of the elbow? Moreover we are aware that each of the six groups of instability (type A or B with acute, recurrent, persistent forms) includes instability with different severity, requiring different treatments, and therefore, a straightforward treatment algorithm cannot be proposed using this classification.

Despite some limitations, we think this classification can be a useful tool for a better understanding of elbow instability in its various forms. We hope it will be useful to define a universal terminology that will avoid diagnostic misunderstandings and help to compare case series. We also think that the feedback and suggestions from other authors will help to improve the classification further.

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First Episode of Dislocation and Simple Instability: Management and Rehabilitation

11

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11.1 Epidemiology

The elbow is the second most commonly dislocated joint after the shoulder in adults, and the first in the pediatric population (Kuhn and Ross 2008).

Elbow dislocations constitute 10–25% of all injuries to the elbow. The mean age of an individual sustaining this injury is 30 years. There is a male predominance with 2–2.5 times that of females. In a study with the largest reported cohort of patients who underwent simple elbow dislocations, the mean annual incidence rate was 2.65 per 100,000 person-years in Ontario, Canada, for individuals ≥16 years old (Mayne et al. 2015). Other 2 studies report an incidence of simple elbow dislocations within the general population at 6.1 and 5.21 per 100,000 person-years, respectively (Josefsson and Nilsson 1986; Stoneback et al. 2012).

Approximately 40% of elbow dislocations occur during sports. Gymnastics, wrestling, basketball, and football are commonly involved. An interesting study about the epidemiology of this type of injury reported an incidence of 0.38 per 100,000 injuries in high school athletes, with a male prevalence of 91.3% (Dizdarevic et al. 2016).

11.2 Classification and Mechanism of Injury

Elbow dislocations are classified as simple or complex. In a simple elbow dislocation bone or cartilage is not involved, although small avulsion fractures may be present, and the joint is stable when put through full range of motion after repositioning (Anakwe et al. 2011). Complex dislocations are associated with fractures of the olecranon, radial head, or coronoid process (Cohen and Hastings 1998).

Elbow dislocation has also been classified depending upon the direction of displacement of the ulna relative to the humerus. Five patterns of dislocation have been described: posterior, lateral, medial, anterior, and divergent.

11.2.1 Posterior Dislocation

Is the most common pattern. The common mechanism of injury is a fall on the outstretched arm, that produces an axial force on the elbow as it flexes. As the body internally rotates on the hand and approaches the ground, external rotation and valgus moments are applied to the elbow causing the dislocation (Fig. 11.1). (O'Driscoll et al. 1992a, b). If the forearm is displaced medially or laterally, a posteromedial or posterolateral dislocation may occur.

11.2.2 Anterior

It's an uncommon injury which occurs after a direct high-energy blow to the posterior aspect of the forearm with the elbow in 90° of flexion (Quintero and Varecka 2008). Associated fractures are very frequent, especially of the olecranon.

11.2.3 Medial, Lateral, and Divergent

They are infrequent and are usually associated with high-energy trauma.

11.3 Pathological Anatomy

The disruption of soft tissues in simple elbow dislocation can be classified in 3 stages as postulated by O'Driscoll et al. (2001).

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Stage 1 is characterized by the total disruption of the lateral ulnar collateral ligament and the partial or total disruption of the remaining lateral collateral ligament complex, resulting in posterolateral rotatory subluxation of the elbow. Patients feel pain when varus stress is applied to the elbow.

Stage 2 includes the disruption of the anterior capsule that results in incomplete elbow dislocation in a posterolateral direction. X-rays may show a coronoid process perched on the humeral trochlea. Reduction is usually very easy and often it is obtained by patients bending the elbow.

Stage 3 is divided into two subgroups:

(a) Disruption of all soft tissues surrounding and including the posterior part of the medial collateral ligament except for the anterior bundle. This bundle forms the pivot around which the elbow dislocates in a posterior direction by way of a posterolateral rotatory mechanism;
(b) Complete disruption of the medial collateral ligament complex of the elbow.

Another model described by Ring and Jupiter (Ring and Jupiter 1998) divides the stabilizing factors into anterior, posterior, medial, and lateral columns. The risk of chronic instability increases with the amount of columns injured.

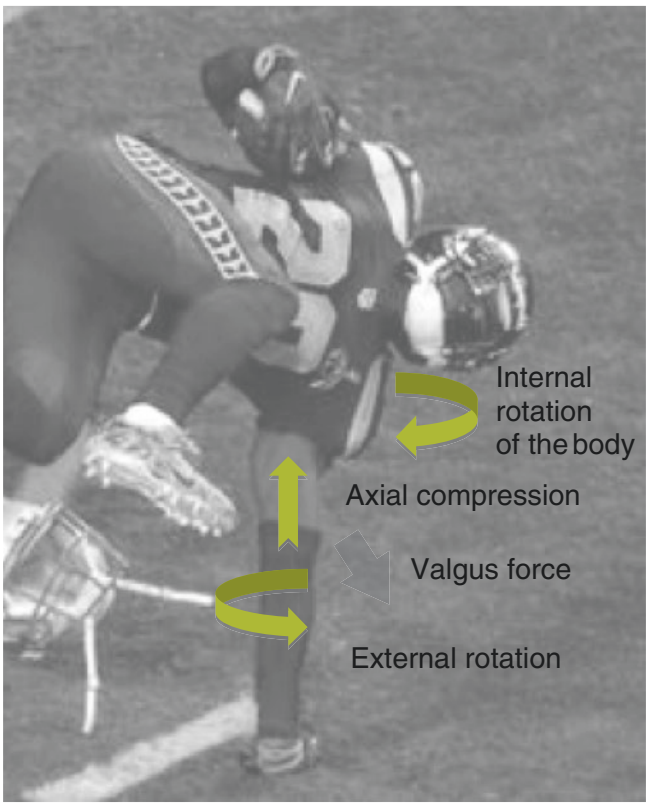


Fig. 11.1 Example of a fall on the outstreched arm during professional sport activity. The combination of internal rotation of the body, the axial compression, valgus force and external rotation of the elbow due to the hand pointed to the ground produce the dislocation

11.4 Clinical Findings and Radiological Examination

A through and detailed history should attempt to elicit the type of the trauma, the mechanism of injury, impact and post-traumatic neurological symptoms.

The examination should start with inspection. Bruising and swelling on the medial or lateral side of the elbow suggests injury to the underlying soft tissue and bony structures (Fig. 11.2). Tenderness on palpation further suggests injury. A neurovascular examination should always be performed.

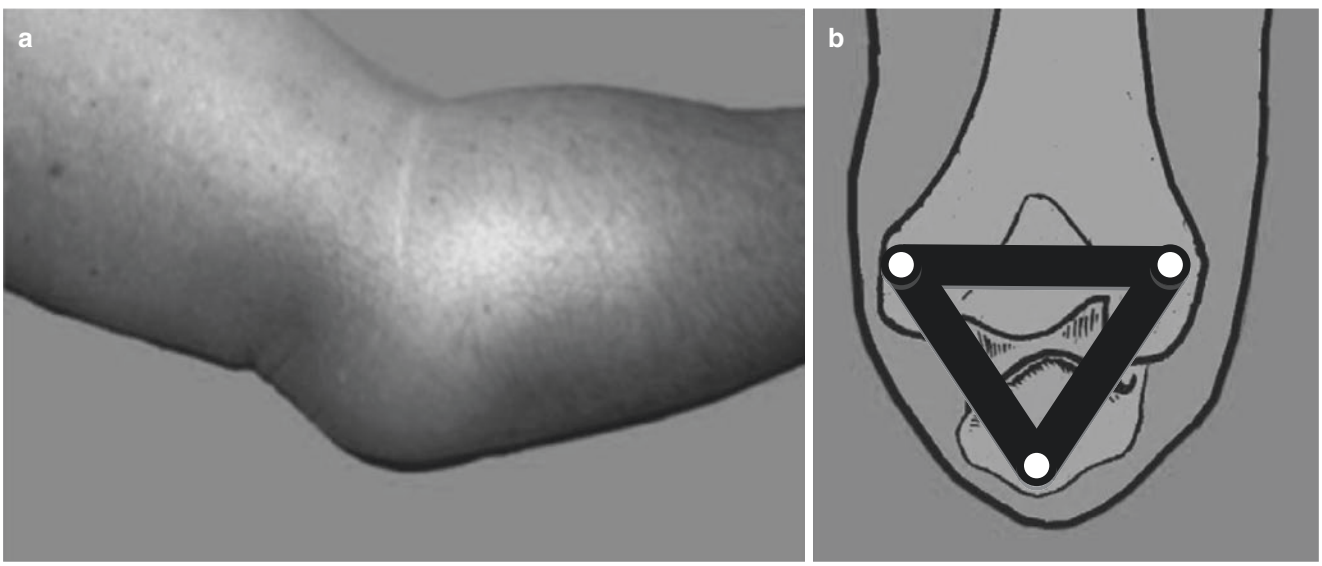


Fig. 11.2 Clinical aspect of a dislocated elbow with swelling and deformity (**a**). Triangular relationtship between olecranon and humeral epicondyles (**b**)

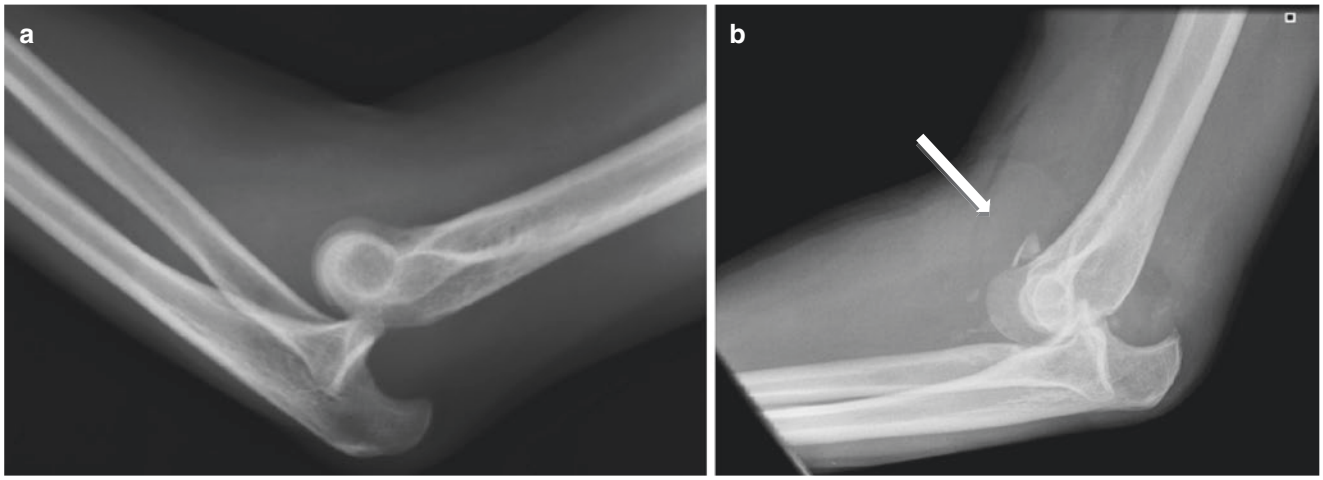


Fig. 11.3 X-Ray of a simple elbow dislocation (**a**). X-ray of dislocated elbow with coronoid fracture (*arrow*), displaced (**b**)



Fig. 11.4 MRI showing tear of the medial collateral ligament (*arrows*)

In posterior dislocation the patient typically presents with a shortened forearm that is held in flexion with a prominent olecranon posteriorly. Disruption of the triangular relationship of the tip of the olecranon with the distal humeral epicondyles in the injured elbow, when comparing the injured elbow with the unaffected side, can help to confirm the diagnosis clinically (Fig. 11.2b).

It is crucial to make a correct and quick diagnosis in order to reduce the dislocation immediately, preventing dangerous complications due to nerve or vessel compression or severe swelling of the arm.

Two-dimensional X-ray images should be taken before the reduction in order to choose the correct repositioning maneuver and to avoid displacement of any co-existing fractures (Fig. 11.3).

MRI provides a substantial contribution in the diagnosis and "decision making" of elbow dislocations (Fig. 11.4), with a sensitivity of 60% (80% in artroRMN) and a specificity of 100% (Schwartz et al. 1995). More controversial is its value in the posterolateral rotatory instability. In fact, while Potter (Potter et al. 1997) has found a 100% correlation between abnormalities of LCL on MRI and clinical instability, other authors (Carrino et al. 2001; Grafe et al. 2003) have pointed out the difficulties in uniquely identifying this band of the ulnar collateral ligament (Fig. 11.4). The diagnosis of lateral instability remains clinical, confirmed by testing the elbow under anesthesia.

The TC has more limited indications in simple elbow dislocations, but it is useful to rule out a bone involvement.

11.5 Reduction, Radiological and Clinical Assessment

Simple elbow dislocations are initially managed with closed reduction.

The principles of reduction are adequate patient sedation, correction of medial-lateral deformity or displacement, longitudinal traction in flexion before the olecranon is levered over the distal humerus.

Muscle relaxation is the key to joint reduction. Care has to be taken to avoid multiple attempts at reduction, which would increase the risk for chondral injuries.

Reduction can be performed under general, regional, or local anesthesia or even without anesthesia, depending upon the preference of the surgeon. Perched dislocation can be

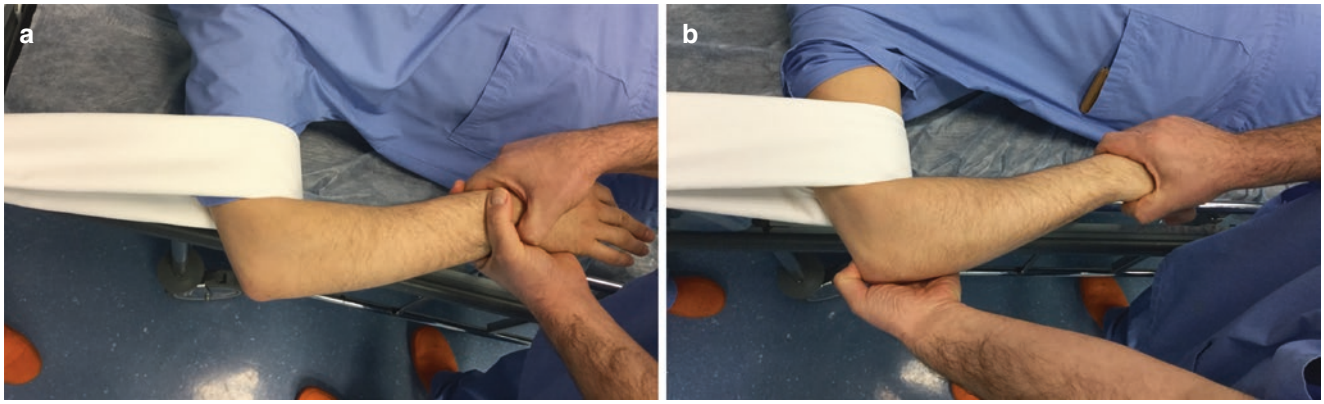


Fig. 11.5 Reduction maneuver: traction is applied on the forearm and a countertraction on the humerus (**a**). A thumb can help to achive reduction (**b**)

treated with intraarticular analgesia and sedation, whereas a complete dislocation may require general anesthesia and a muscle relaxant. Is better to perform reduction under general anesthesia in order to avoid excessive traction on the joint and possible fractures, in particular of the coronoid process. Reduction should be obtained with the forearm in complete supination in order to avoid additional trauma to the medial compartment.

A prone traction and countertraction maneuver is often successful (Fig. 11.5a) (Ross et al. 1999) Reduction is usually achieved by extending the elbow with countertraction on the arm, and a thumb is used to manipulate the coronoid, clearing the trochlea (Fig. 11.5b).

Dislocations irreducible with closed reduction are quite uncommon and are frequently associated with soft tissue interposition or fractures. In an irreducible dislocation without fractures, the radial head gets trapped in the soft tissues of the forearm or maybe interposed through the forearm fascia. These kind of dislocations require surgical intervention.

A congruent reduction should be confirmed clinically and radiographically and the elbow should be gently taken through a range of movement (ROM) in the flexion-extension plane to assess the stable range and to unmask any gross instability.

On a true lateral radiograph, lateral ligament instability may be identified by subtle opening of the trochlea/trochlea notch interval, which is referred to as the "tilt sign"(Watts and Bain 2010).

In the posterolateral rotatory instability, the standard projections (AP and LL) are useful to rule out avulsion fractures at the origin or insertion of the lateral ligament complex and to evaluate the integrity of the radial head, coronoid and capitulum humeri. A ulnohumeral distance >4 mm ("drop sign") (Coonrad et al. 2005) on lateral radiographs, without applying stress, is indicative of residual instability (Fig. 11.6).

The following procedure can be used in emergency room for testing for elbow ligamentous instability. The patient's arm should be positioned under the radiograph intensifier. Humero-ulnar joints should be examined during valgus and varus stress tests at the flexion angles of 0°-30°-60°-90° under the radiograph intensifier (Fig. 11.7) (Mayne et al. 2015).

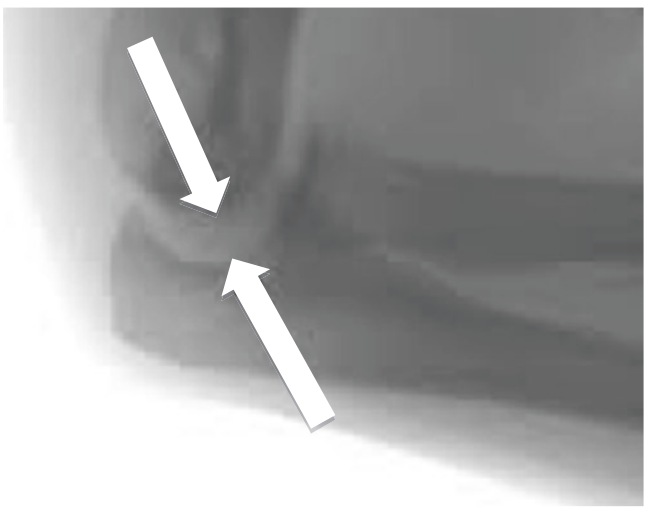


Fig. 11.6 Presence of a ulno-humeral distance > 4 m after reduction, the "Drop Sign"

11.6 Specific Clinical Tests

11.6.1 Pivot-Shift Lateral Test

Pain, anxiety, and possible subluxation of the radial head are evocated applying a force on the elbow in valgus, external rotation and axial load (O'Driscoll et al. 1991) (Fig. 11.8).

11.6.2 Posterolateral Rotatory Drawer Test

With the patient supine, limb at head and elbow flexed to 90°, the application of a force in the anteroposterior direction of the radius and ulna generates apprehension in an unstable elbow (O'Driscoll 1999) (Fig. 11.9).

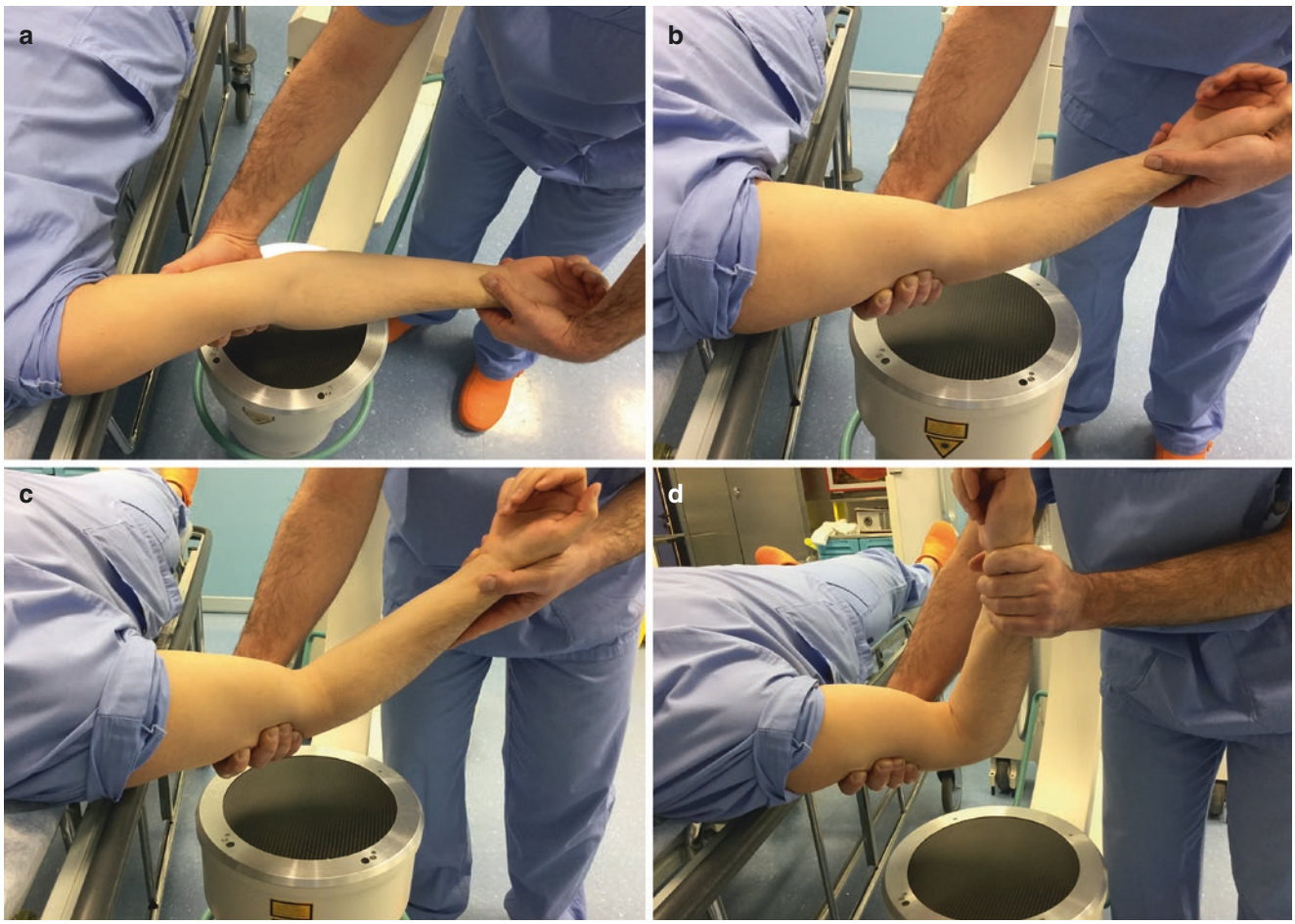


Fig. 11.7 Varus and Valgus stress are tested under a radiologic intensifier at 0 (**a**), 30 (**b**), 60 (**c**) and 90 (**d**) degrees of flexion after reduction



Fig. 11.8 Pivot-shift lateral test



Fig. 11.9 Posterolateral rotatory drawer test

11.6.3 Table-Top Relocation Test

The patient performs a slow drop on the edge of a table using only one arm, with the forearm in supination; in the presence of instability, apprehension appears at 40° of flexion (Fig. 11.10) (Arvind and Hargreaves 2006).

11.6.4 Chair Sign

The patient, in sitting position, with the elbow flexed to 90° and forearm supination, are try to rise from his chair with his arms just pushing down; an external ligament insufficiency generates strong apprehension or dislocation

of the radial head when the elbow is extended (Regan and Lapner 2006) (Fig. 11.11).

In patients with MCL injury, the elbow should be tested for the valgus instability between 30° and 70° flexion because the medial ligament complex gives the maximum contribution to the stability valgus at 70° of flexion. The valgus stress test is performed by applying a force on the elbow in valgus simultaneously performing flexion-extension with the shoulder abducted and externally rotated. The test is positive if pain is evoked within the flexion arc of 80–120° (Eygendaal and Safran 2006) (Fig. 11.12).

Another test is the "milking maneuver" (Fig. 11.13), which is performed with the elbow at 70° of flexion and the examiner who, with one hand palpates the medial joint line and the LCM, and with the other hand grabs the thumb of the patient, performs a valgus forces. The test is positive if the examiner feels a clear opening of the medial joint line (Eygendaal and Safran 2006).

A neuropathy of the ulnar nerve may underlie in medial elbow instability. The nerve should be palpated in the cubital tunnel and any sensory and motor deficits should be ruled out (Merolla et al. 2008).



Fig. 11.10 Table top relocation test



Fig. 11.11 Chair sign



Fig. 11.12 Valgus stress test



Fig. 11.13 The "milking maneuver"

11.7 Acute Treatment

The goal of treatment in all dislocations is to obtain a concentric and stable reduction to allow early movement of the elbow joint and to restore function.

11.7.1 Conservative Treatment

Following reduction, it is imperative to clinically assess the range of motion (ROM) and stability of the joint (Fig. 11.14) and to radiologically assess the congruency of reduction. If the elbow is unstable, the point of instability should be assessed by noting the degree of flexion when the elbow redislocates. If the elbow is stable through the full ROM, a brace is provided for comfort and the patient is encouraged to mobilize the elbow (Fig. 11.15). If the elbow subluxes or dislocates in extension, the stability should be assessed with the forearm in pronation. If this restores stability, a hinged brace is applied with the forearm being maintained in full pronation. If the elbow result still unstable, it is necessary to limit the extension of the brace to 30°. If the elbow remains unstable surgery is the necessary treatment option (O'Driscoll et al. 2001).

The patient is assessed at weekly intervals and the extension-block gradually decreased, aiming for full extension by 3–6 weeks. Radiographs should be taken after the first week to assess the congruency of reduction as late subluxation may occur.

Early range of motion needs to be adjusted according to the injured ligament. Immobilization of the elbow for >3 weeks is associated with the development of a fixed flexion contracture (Mehlhoff et al. 1988).

After the 6th week, free range of motion with lightweight should be possible. And range of motion is then expanded by 10° per week according to a patient's pain symptoms.

11.7.2 Surgical Treatment

The primary goal of surgical treatment is to achieve stability to allow early ROM. The indications for surgery include failure to obtain and maintain a congruent reduction, persistent instability of the joint requiring immobilization beyond 30–45 degrees of flexion (O'Driscoll et al. 2001), and suspected entrapment of intraarticular fragments or neurovascular structures in the joint. Acute repair may also



Fig. 11.15 Telescopic brace for early elbow motion

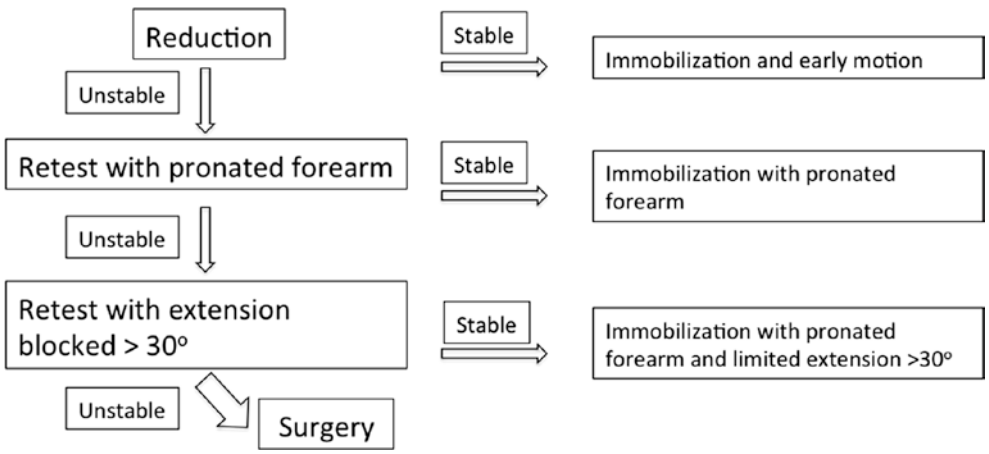


Fig. 11.14 Conservative treatment algorithm of simple elbow dislocations

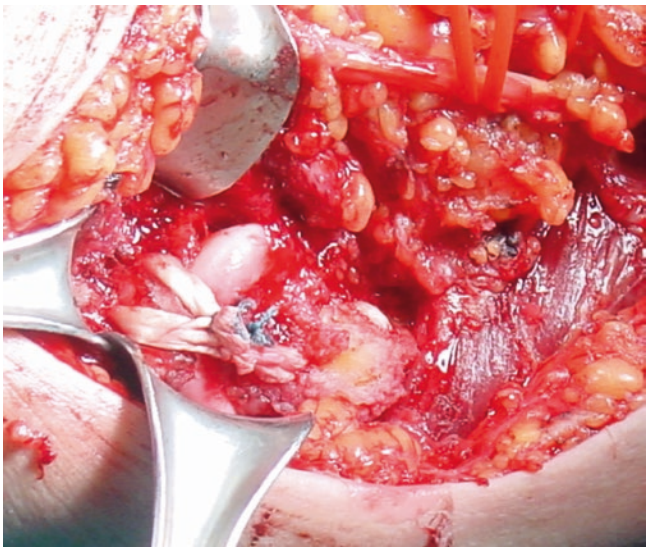


Fig. 11.16 Reconstruction of the MCL with tendon-allograft

be indicated in high-level athletes who cannot afford to miss large portions of the athletic season.

Ligaments may have been avulsed and can be repaired directly to the bone. The direct repair is performed in the proximal avulsion (humeral) ligament which has to be of acceptable quality and free of calcification in context.

We proceed to suture the residue tissue, possibly with eight shape suture; in avulsions lesions, a Bunnell suture attached to the periosteum with transosseous points to the epicondyle is performed. In the elbow with an acute PLRI, arthroscopic repair of the avulsed ligament complex can be very efficacious. One common finding is the ability to move an arthroscope placed down the posterolateral gutter from the posterior central portal straight across the ulnohumeral articulation into the medial gutter. This maneuver is not possible in a stable elbow, and is termed the "drive through sign." Once the area of damage has been defined, an arthroscopic anchor may be placed into the humerus at the site of origin of the torn ligament for repair.

In cases where the ligament appears insufficient and of poor quality, reconstruction is necessary (Fig. 11.16).

The alternative to ligament repair is the application of a hinged external fixator (O'Driscoll et al. 2003; Ring and Jupiter 2005; Tan et al. 2005).

11.8 Complications

11.8.1 Instability

Sometimes, elbow dislocations categorized as stage 1 and stage 2 are underestimated. Insufficient clinical and radiological examinations may classify an injury as a distortion, and the patient is discharged without any further treatment.

Ruptured collateral ligaments result in hyper-mobility of the elbow joint; this condition leads to the very painful over-compensation of the extensor muscle group (Eygendaal et al. 2000).

11.8.2 Stiffness

Limitation of extension is common following dislocation. In the first 6 months, bracing and physical therapy are helpful in regaining lost motion. Inflammatory reactions of the healing process are responsible for capsulitis and shrinkage of the capsule by SMA myofibroblasts (Germscheid and Hildebrand 2006).

Capsular fibrosis can be reduced or stopped by the oral administration of cortisol and spironolactone (Brandt et al. 2011; Li et al. 2007).

If there is limitation of 30° or more, contracture release may be considered. The anterior capsule is often thickened and shortened. It can be released through a lateral incision or arthroscopically. In either case, there will likely be scar tissue and adhesions posteriorly that also need to be removed. An ulnar nerve decompression may be necessary.

11.8.3 Heterotopic Ossification

Heterotopic ossification (HO) in the lateral and medial collateral ligaments or anterior capsule occurs frequently and occasionally may be sufficient to cause marked functional impairment.

Risk factors for HO are the time elapsed between trauma and surgery as well as the number of days of immobilization after surgery (Bauer et al. 2012).

Anti-inflammatory drugs, such as indomethacin and radiation therapy, are used as part of the pre- and post-surgical therapy of elbow dislocations to prevent HO (Keschner and Paksima 2007).

11.8.4 Compartment Syndrome

Intramuscular bleeding and edema formation within the flexor compartment of the forearm may lead to compartment syndrome, especially if associated vascular injury. Compartment pressure measurements are indicated when the diagnosis is suspected. An early and adequate anterior decompression sectioning the lacertus fibrosus and the lower brachial and forearm fascia is necessary.

11.8.5 Osteochondral Injuries

Loose bodies within the joint following reduction usually represent inclusion of an avulsed fragment of the medial epicondyle or a fragment of the articular surface. The fragments can be fixed or removed with arthroscopic or open surgery.

11.8.6 Neurovascular Complications

Neurologic problems occur in approximately 20% of dislocations, with the ulnar nerve mostly involved. Symptoms vary from transient paresthesias in the ulnar distribution to permanent ulnar palsy. Median nerve symptoms are less common and also range from a transient to a complete palsy.

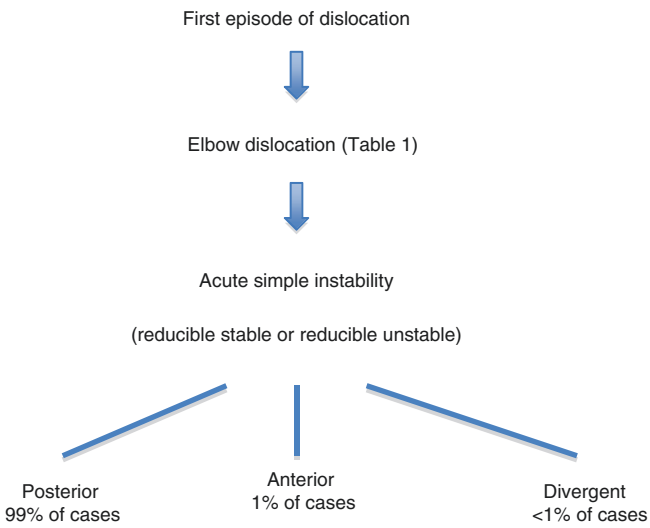
These injuries must be differentiated from secondary compressive injuries.

Fibrosis or ossification around the cubital tunnel may lead to delayed compression of the ulnar nerve.

Stretching and distortion of the anterior structures may result in spasm, intimal damage, thrombosis, or rupture of the brachial artery.

11.9 First Episode of Dislocation and Simple Instability Rehabilitation

Subluxations/dislocations and instability are summarized in Table 11.1:



After a first acute dislocation, the patient may experience simple dynamic instability with loss of congruence arising immediately post-trauma, or later due to overuse. Dynamic instability secondary to trauma or overuse may be posterolateral or in valgus stress. Posterolateral rotatory instability (PRLI) is more common in overhead players, whereas in weight lifters it occurs more often under valgus stress. According to O'Driscoll the lesion begins laterally and extends medially; however, more recent studies also describe a mechanism of injury that starts medially.

Table 11.1 Elbow dislocation and elbow instability (Rotini 2014)

Trauma severity	Simple instability	Complex instability	
Elbow dislocation			
Direction and mechanism of injury	Posterior: (99%) PLRI PMRI Direct posterior in valgus	Anterior (1%)	Divergent (<1%)
Timing	Acute: Reducible stable Reducible unstable	Chronic: Unrecognized Not adequately treated	Recurrent
Elbow instability			
Trauma severity	Simple instability	Complex instability	
Direction and mechanism of injury	PLRI: Post-traumatic Overuse	Valgus stress: Post-traumatic Overuse	
Timing	Acute: Post-traumatic	Chronic: Post-traumatic Overuse	

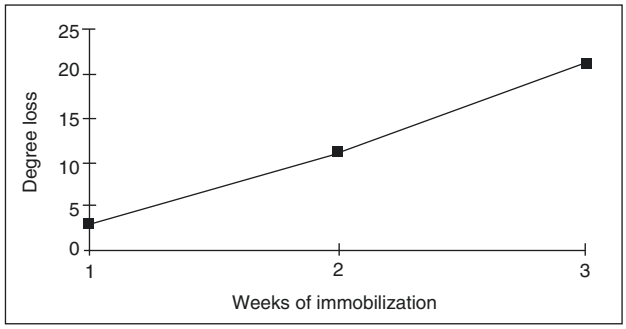
A patient with a first episode of elbow subluxation is taken to the Emergency Department and X-rayed, and the dislocation is reduced.

Be it dislocation or instability, the physical therapist needs to be aware precisely of the ligament lesion to be treated and of the direction and mechanism of injury of the dislocation and/or instability. Clearly, the elbow of a patient presenting for rehabilitation has already been reduced and is stable. A joint that is found to be unstable after reduction is managed by surgical reconstruction of the injured ligaments, and the patient is referred to the rehabilitation therapist afterwards.

Immobilization in a brace is the subsequent step both after closed reduction and after surgery. We agree with the literature that the elbow joint should be immobilized for as short a time as possible. This requires a functional brace rather than a plaster cast, to enable passive exercise to be initiated on the 3rd-4th day (Merolla et al. 2013; REgan et al. 1991; De Haan et al. 2010; Merolla et al. 2014). The brace will have to allow some range of movement (ROM) while preventing full extension and flexion (Fig. 11.1).

This is essential to avoid post-traumatic stiffness, which added to the trauma itself may induce irreversible joint damage. A mobile and excessively elastic elbow may require prolonged immobilization.

As illustrated by Protzmann's diagram (Protzmann 1980), prolonged immobilization involves severe ROM loss:



Protzmann	No.	Weeks of immobilization	Degree loss
	27	1	3
	13	2	11
	7	3	21
Total	47		8

There is broad consensus that postoperative elbow position in the brace should be:

- passive supination for medial collateral ligament (MCL) lesions (Alolabi et al. 2012; Pichora et al. 2007; Pichora et al., 2007) or
- passive pronation to stabilize ulnar collateral ligament (UCL) injuries(Alolabi et al., 2012; Pichora et al., 2007; Pichora et al., 2007).



Fig. 11.17 Hinged brace set to the ROM degrees indicated by the surgeon

However, in our experience these positions may be uncomfortable and cause pain even at rest. In patients where the pain exceeds the benefit of immobilization, bringing the forearm to an intermediate position should therefore be considered, because pain can induce a state of general limb contraction that has the potential to hamper the rehabilitation process.

The focus of treatment should be the patient, not the condition. For this reason guidelines should not be followed rigidly, but adapted to each patient's requirements.

11.10 Conservative Management

Passive mobilization can be initiated on the 3rd day. This does not mean that the brace is no longer needed, but that during sessions it will be removed by the therapist to enable passive mobilization, where the therapist will test movements to prevent stiffness development. The brace will be replaced at the end of the session.

Patients with a wide range of conditions are referred for rehabilitation. The physical therapist needs to be aware of each patient's history after the first subluxation, because it may affect recovery. For instance, a patient who is wearing a hinged brace will not experience problems due to immobility, and the therapist will focus on stability and strength recovery (Dunning et al., 2001a; Dunning et al., 2001b) (Fig. 11.17).

At this time the physical therapist can begin continuous passive motion exercises with elbow flexion and extension as suggested by O'Driscoll (2002), to achieve full ROM recovery. Careful instruction will enable the patient to do self-assisted exercises avoiding joint crepitus and pain (Wolf and Hotchkiss 2006) (Figs. 11.21 and 11.22).

Patients who have received conservative immobilization in a cast for 2 weeks present with painful stiffness and the elbow joint blocked at 90°, with a narrow ROM both in flexion and extension. In such cases recovery of nearly complete passive flexion and extension in a month predicts a successful outcome; otherwise surgery is recommended, because the trauma has been compounded by immobilization injury and the time for recovery will have expired. In contrast, patients who despite cast immobilization need to recover no more than 30° have a much more favorable prognosis.

Patient age is clearly a key factor. The functional requirements of young, athletic patients are much greater than those of subjects aged more than 45 years. The priority goals in a young patient will be stability and ROM recovery. Therefore, waiting for more than 60 days post-trauma for conservative treatment to achieve recovery may be counterproductive, especially in presence of a very narrow ROM (de Haan et al. 2010,c). Surgical debridement and ligament reconstruction are recommended in such patients (Fig. 11.18).

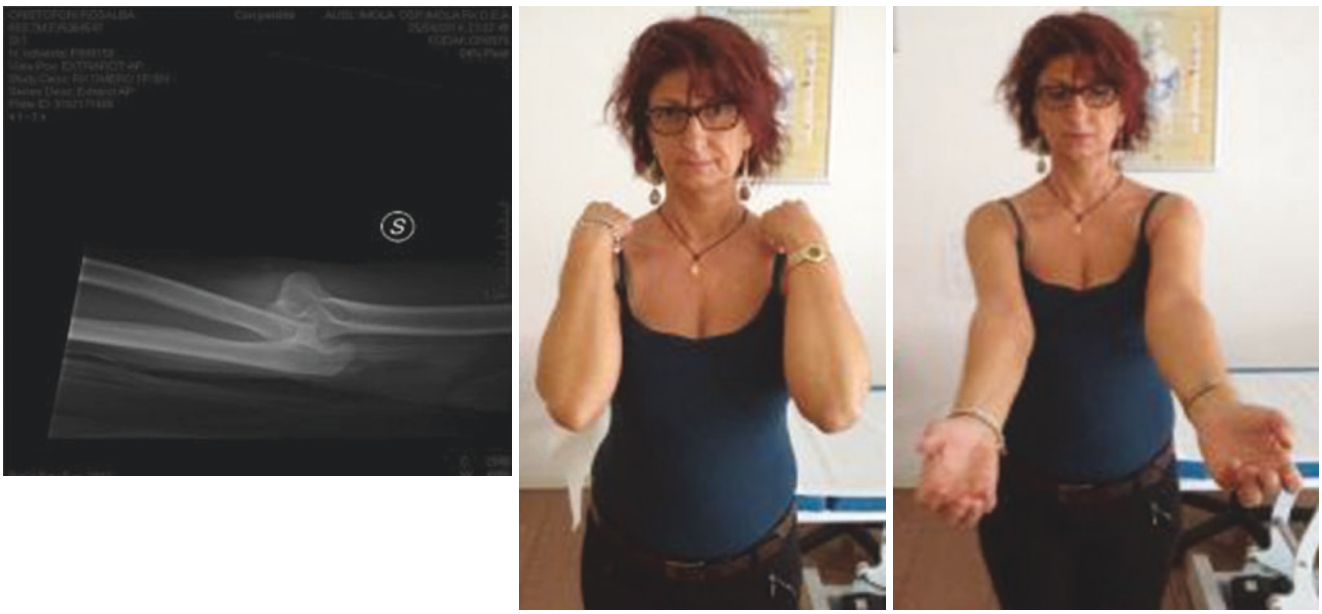


Fig. 11.18 A patient with simple traumatic subluxation of the left elbow and a UCL lesion treated conservatively by immobilization in a brace

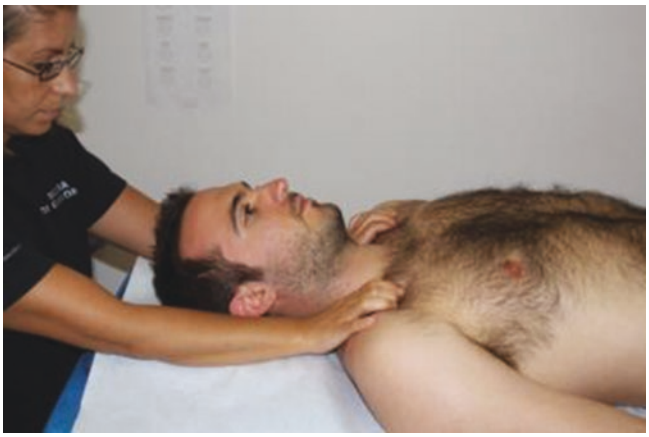


Fig. 11.19 Clavipectoral fascia release to mobilize and drain the Upper Thoracic Outlet



Fig. 11.20 General scapular mobilization to promote upper limb drainage

In a patient with simple traumatic subluxation of the left elbow and a UCL lesion treated conservatively by immobilization in a brace, rehabilitation begun on the 3rd day post-trauma allowed gradual but full ROM recovery. The only problem in these patients will be the recovery of full extension and the removal of any painful joint crepitus associated with movement (Bernas et al. 2009). Even though joint extension will not be a problem, end-ROM positions should not be stimulated during the first 30 days, since flexion beyond 90° could strain the injured ligament. Over the first few days from surgery/trauma, the therapist will therefore apply isometric flexion exercises carefully avoiding elbow flexion exceeding 90° (Bernas et al. 2009). These patients greatly benefit from drainage of the upper thoracic outlet (UTO) (Fig. 11.19) and scapular mobilization (Fig. 11.20) to reduce the edema and hematoma (Fusaro et al. 2014). Given the neurological and embryological connections of the upper limbs with the cervical area, especially the cervical spine, attention should also focus on this area.

Conservative recovery of an elbow with simple instability involves several stages:

Stage 1 self-assisted mobilization for full ROM restoration (Park et al. 2013)

- isometric contraction exercises for elbow, forearm, and shoulder
- isometric contraction of elbow flexors; varus movements reduce the load on the lateral collateral ligament(Park et al. 2013)

Stage 2 introduction of isometric contraction exercises for extensors and supinators

- gentle, gradual active pronation and supination exercises to stabilize muscle tone before activation of the biceps muscle



Fig. 11.21 self assisted mobilization in sitting position for gravity-assisted elbow extension



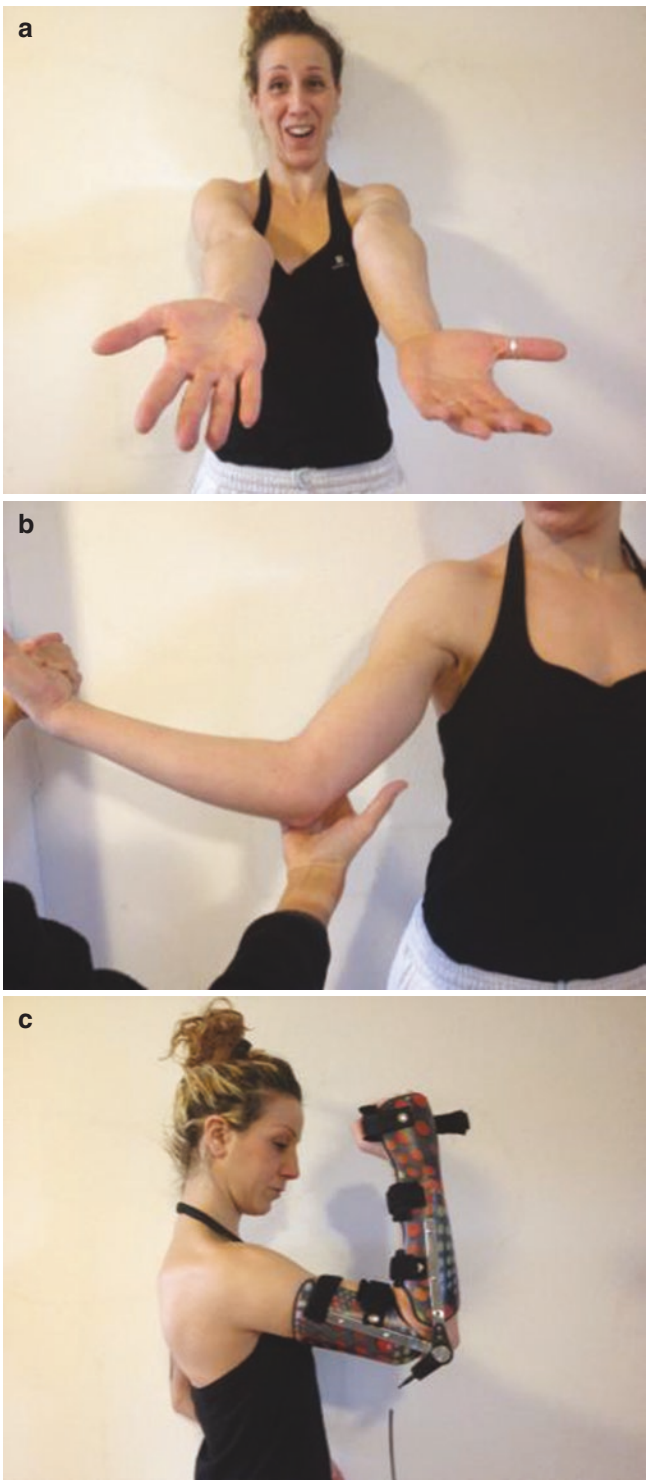
Fig. 11.22 self assisted mobilization in supine position for gravity-assisted elbow flexion

- contraction of the anconeus muscle (Molinier et al. 2011) against low-level elastic resistance (Fig. 11.24); prolonged contraction is however required, because this extensor has deep fibers that reach the capsule, connecting the ulna to the humerus; it is always activated by pronation/supination and in extension it is activated before the triceps(Molinier et al. 2011),
- introduction of scapulothoracic stability exercises
- initiation of exercises for humeral head rotation, particularly internal rotators (subscapularis), to recover the throwing motion and stabilize the humeral head for arm cocking

Stage 3 strengthening exercises for all elbow and shoulder muscle groups

- neuromotor control with plyometric exercises
- eccentric contraction exercises (Ellenbecker and Mattalino 1997; Shanley et al. 2011)
- humeral biceps strengthening
- recovery of the technical movement with appropriate exercises.

In this phase of conservative recovery, patients experiencing severe elbow joint instability even at rest can use hinged braces with straps, stays, and pads to support the joint and permit movement by guiding it in directions that are as physiological as possible, avoiding pain in end-ROM positions and strain on the injured ligaments in this very sensitive phase (Photos A, B, C, D, E).



A;B;C: a woman with medial elbow instability; during conservative recovery the instability is managed by a brace with a medial stay to avoid strain on the medial compartment.



D;E: a volleyball player with painful end extension during recovery of the motion; a neoprene brace with hinges and straps was designed to prevent complete extension during sport-specific exercises.

11.11 Management After Surgical Treatment

Correct rehabilitation of patients with a first episode of subluxation managed by surgery—either Ulnar Collateral Ligament or radial ligament reconstruction, involves the following stages:

- immobilization in a functional brace for 2–3 weeks (set to the end-ROM position indicated by the surgeon based on patient age);
- on the 3rd day, introduction of therapist-guided passive mobilization exercise in flexion and extension, carefully avoiding end extension (O'Driscoll 2002); during passive mobilization the hand will be placed in neutral position to avoid pain induced by movements performed in two different planes (e.g., supination/extension or supination/flexion). Passive mobilization will indicate to the therapist whether the tissue is evolving to stiffness or laxity: in the latter case, passive mobilization will be useless in this phase;
- in case of elbow stiffness, warming the joint before sessions using a lukewarm, moist cloth will help predispose it to mobilization (Fig. 11.23);
- beginning on day 10, introduction of active exercises with the elbow flexed at 90°—with emphasis on extension in pronation or supination in relation to the ligament that has been repaired (Pichora et al. 2007; de Haan et al. 2010; Bernas et al. 2009; Molinier et al. 2011) (Fig. 11.24)—and of gravity-assisted exercises for flexion as well as extension (Fusaro et al. 2014; Wolf and Hotchkiss 2006) (Figs. 11.25 and 11.26);
- from the 35th day: exercises in a rehabilitation pool
- from the 45th day: strengthening exercises for the humeral head depressors with resistance applied at the level of the elbow (Fig. 11.27 and 11.28), and for the anconeus muscle



Fig. 11.23 Warming the joint before sessions using a lukewarm, moist cloth will help predispose it to mobilization

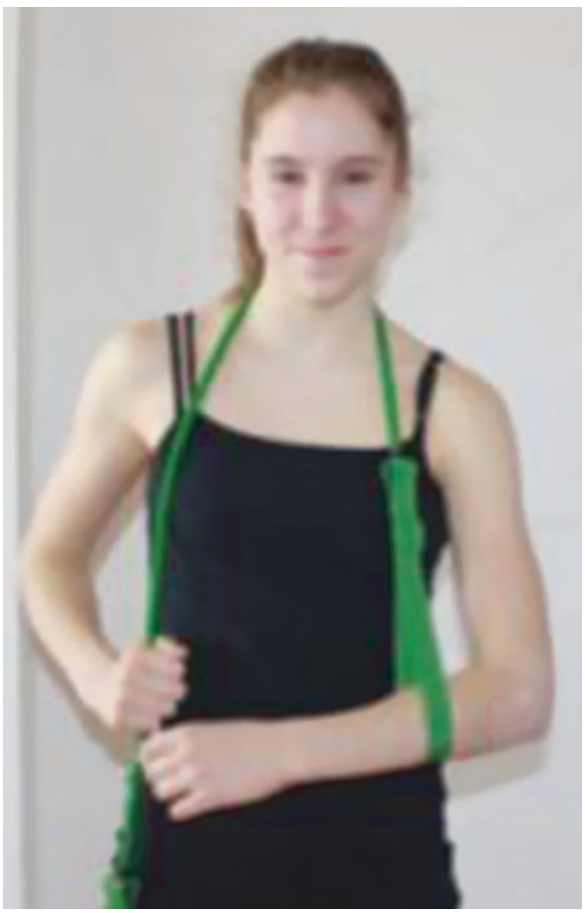


Fig. 11.24 Active extension against elastic resistance with forearm pronation to strengthen the anconeus muscle, whose fibers stabilize the joint

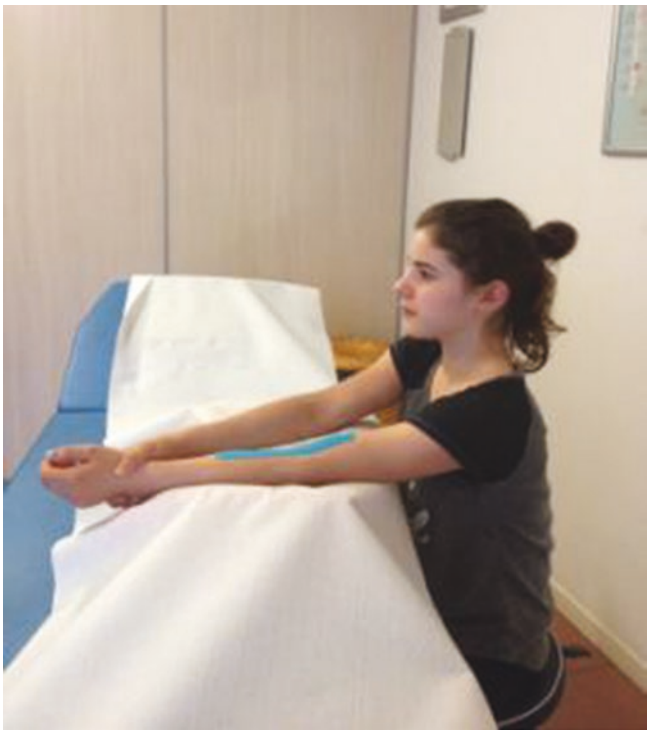


Fig. 11.25 Gravity assisted exercise for extension (in seated posistion)

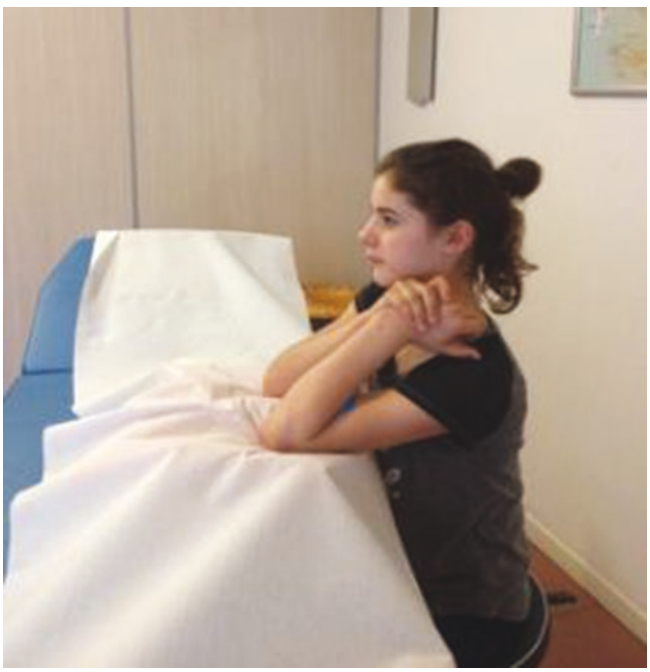


Fig. 11.26 Gravity assisted exercise for flexion (in seated position)

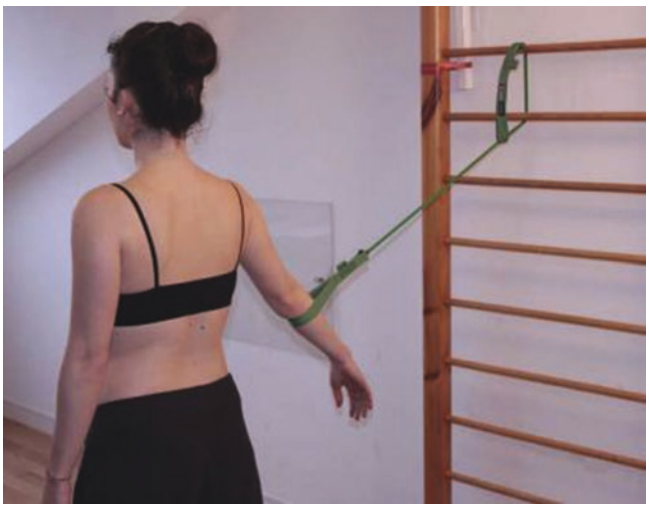


Fig. 11.27 Strengthening exercises for the humeral head depressors with resistance applied at the elbow to avoid straining the elbow muscles starting position



Fig. 11.28 Strengthening exercises for the humeral head depressors with resistance applied at the elbow to avoid straining the elbow muscles, final posistion

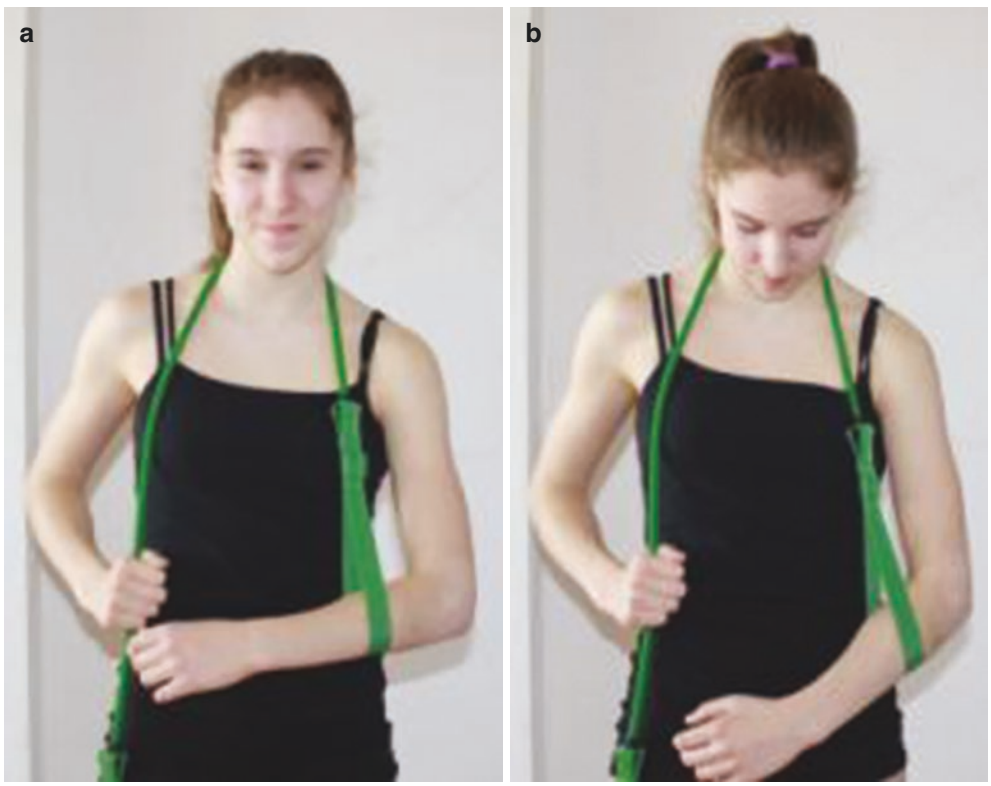


Fig. 11.29 (**a**, **b**) Active anconeus strengthening exercises at an angle between 90° and 120°, to protect the joint

in 90° of flexion with forearm pronation or supination in relation to injury type (Fig. 11.29a, b)

- 70 days from the operation, strengthening exercises for epicondylar and medial epicondylar muscles may be introduced, initially in eccentric contraction, to avoid muscle contracture and pain (Ellenbecker and Mattalino 1997; Shanley et al. 2011); 3 weeks later exercises in concentric contraction can be added (Figs. 11.30, 11.31, 11.32, 11.33, 11.34, 11.35, 11.36, 11.37, and 11.38)

Concentric contraction exercises involve the same sequence as those in eccentric contraction, but are performed in the opposite direction (Figs. 11.39, 11.40, and 11.41):



Fig. 11.30 Starting position in the sequence of a strenghthening exercise for the epicondylar muscles eccentric contraction against elastic resistance (Carli Di Giacomo 2013)

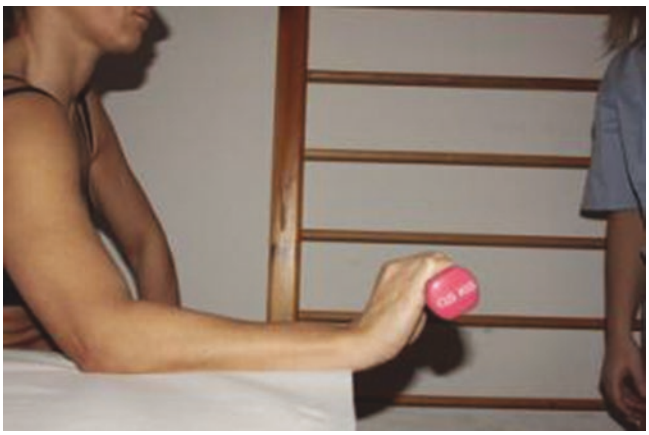


Fig. 11.33 Sequence of a strengthening exercise for the epicondylar muscles in eccentric contraction against isotonic resistance: after phase 3, return to start position without contraction. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

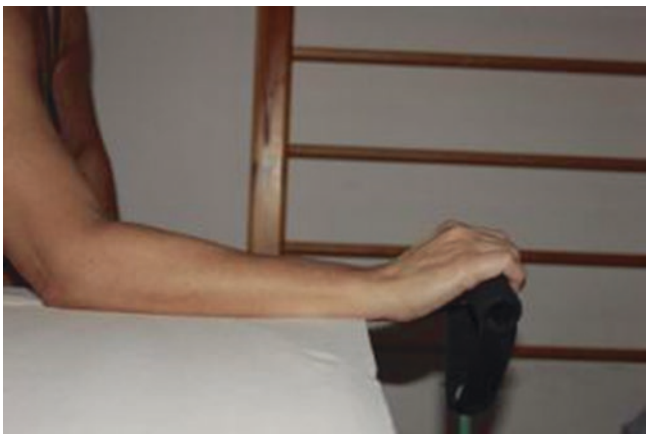


Fig. 11.31 Sequence of a strengthening exercise for the epicondylar muscles eccentric contraction against elastic resistance: phase 2 (Carli et al. 2013)

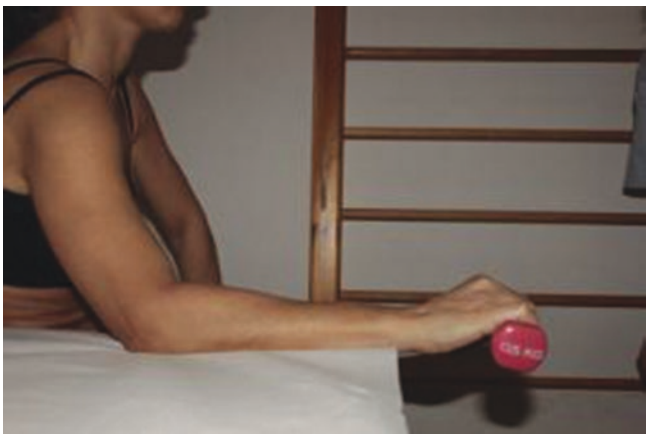


Fig. 11.34 Second phase in the strengthening exercise for epicondylar muscle in eccentric contraction (Carli Di Giacomo 2013)



Fig. 11.32 Sequence of a strengthening exercise for the epicondylar muscles eccentric contraction against elastic resistance: after phase 3, return to start without elastic (Carli et al. 2013). Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 11.35 Third phase in strengthning exercise for epicondylar muscles in eccentric contraction after this phase return to start position without contraction



Fig. 11.36 Sequence of a strengthening exercise for the medial condylar muscle in eccentric contraction against 1 kg resistance: Carli Di Giacomo 2013



Fig. 11.39 Starting position for strengthening exercise in concentric contraction for epitroclear muscles (Carli Di Giacomo 2013)



Fig. 11.37 Sequence of a strengthening exercise for the medial condylar muscle in eccentric contraction against 1 kg resistance: phase 2 (Carli et al. 2013)



Fig. 11.40 Second phase of strengthnenig exercise in concentric contraction for epitroclear muscles (Di Giacomo Carli)



Fig. 11.38 Final position in strenghtening exercise for the medial condylar muscle in eccentric contraction against 1 kg resistance: after phase 3, return to start without contraction (Carli et al. 2013)



Fig. 11.41 3 phase final position in strengthening exercise in concentric exercise for epitroclear muscles. (Carli Di Giacomo 2013)

- from the 80th day post-trauma: final rehabilitation stage; proprioception exercises (proprioceptive neuromuscular facilitation, PNF) in flexion/extension and pronation/supination (Figs. 11.42A, B, C) and exercises aimed at recovery of the overall limb movement schema (Carli et al. 2013).

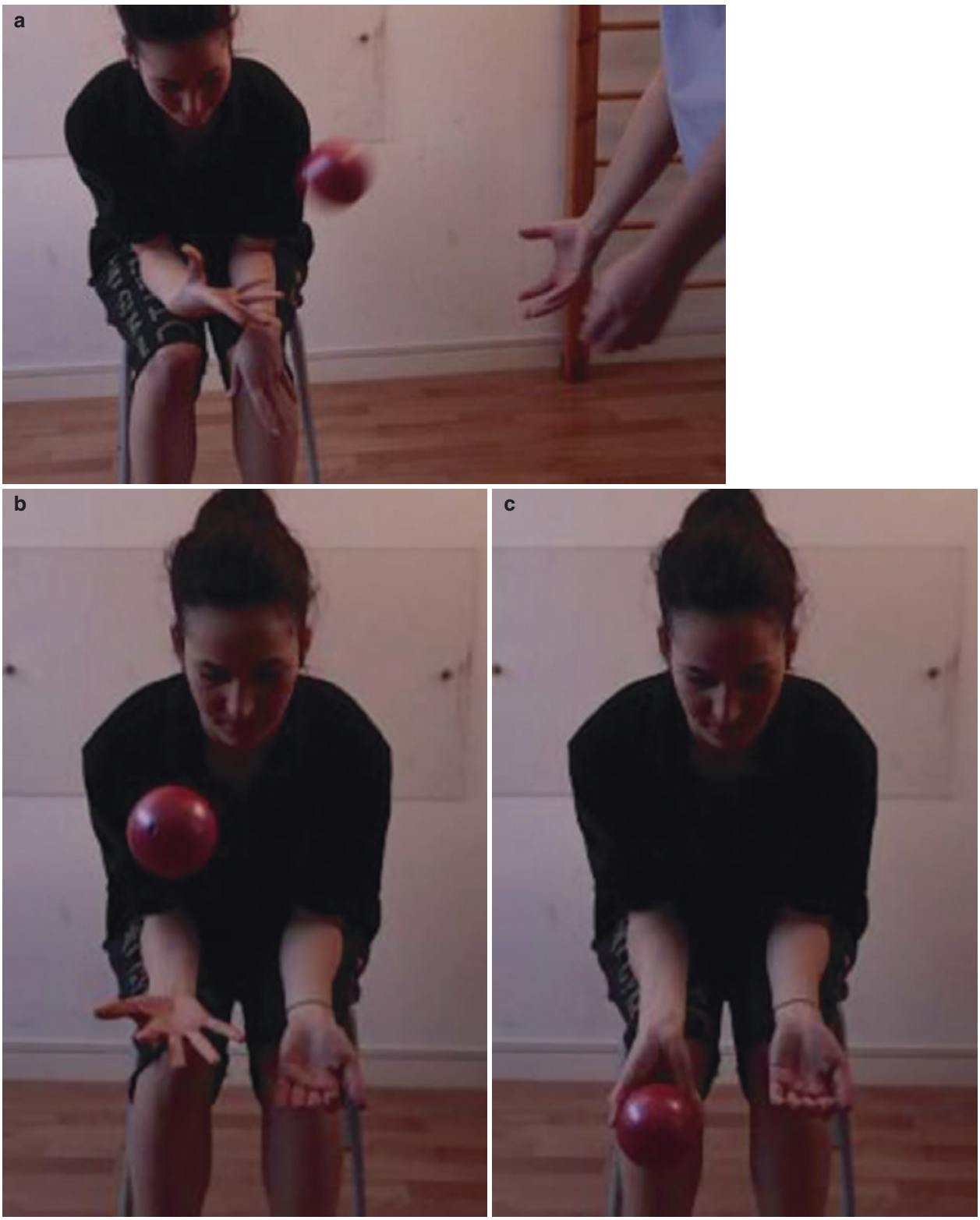


Fig. 11.42 (**a**) PNF exercises based on pronation/supination movements (Carli et al. 2013). (**b**, **c**) PNF exercises based on flexion/extension movements

Strength recovery requires the absence of pain and joint crepitus.

The value of epicondylar and medial epicondylar muscle strengthening exercises in enhancing joint stability has been stressed by several studies, which have extensively investigated the role of these muscles (Lin et al. 2007), how their insertion into the lateral and medial epicondyle affects strength recovery, and how valgus or varus stress can be avoided to protect the ligaments that have been injured or repaired.

11.12 Recovery of the Athletic Gesture

The final stage of the athlete's recovery is return to sport or competitions. Progressive recovery of the sport-specific motion can begin with sport-specific elastic resistance exercises with movement executed at low intensity and speed. Exercises need to involve the whole upper limb and can use a variety of props, tubing and weights for resistance training, and later train specifically the pitching motion, the weight-lifting motion, or the throwing motion, in close coordination with the trainer. The trainer will draw up a general program for the whole body including lower limb, resistance, and explosive strength exercises. Specific upper limb strengthening exercises will need to avoid any valgus or varus stress movement, and rather aim at combining movements performed on different planes, carefully avoiding straining the sutured ligaments. (Figs. 11.43, 11.44, 11.45, 11.46, 11.47, 11.48, 11.49, 11.50, 11.51, 11.52, 11.53, 11.54, 11.55 and 11.56) Clearly, sport-specific exercises will be supplemented with strengthening exercises for:

- internal and external humeral head rotators;
- serratus anterior in prone decubitus;
- medial and lower trapezius bundles;



Fig. 11.43 An athlete performing sport-specific strengthening exercises with elastic and non-elastic resistance; the upper limb movement is trained avoiding all valgus or varus stress; core stability exercises enhance proprioception



Fig. 11.44 An athlete performing sport-specific strengthening exercises with elastic and non-elastic resistance; the upper limb movement is trained avoiding all valgus or varus stress; core stability exercises enhance proprioception

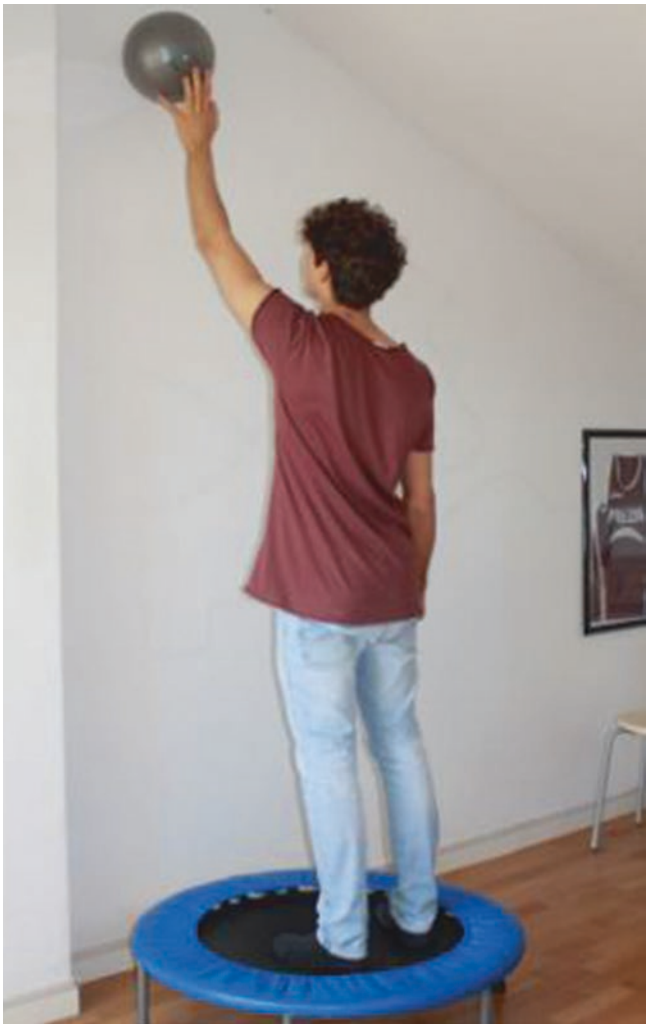


Fig. 11.45 An athlete performing sport-specific strengthening exercises with elastic and non-elastic resistance; the upper limb movement is trained avoiding all valgus or varus stress; core stability exercises enhance proprioception



Fig. 11.46 An athlete performing sport-specific strengthening exercises with elastic and non-elastic resistance; the upper limb movement is trained avoiding all valgus or varus stress; core stability exercises enhance proprioception



Fig. 11.47 An athlete performing sport-specific strengthening exercises with elastic and non-elastic resistance; the upper limb movement is trained avoiding all valgus or varus stress; core stability exercises enhance proprioception

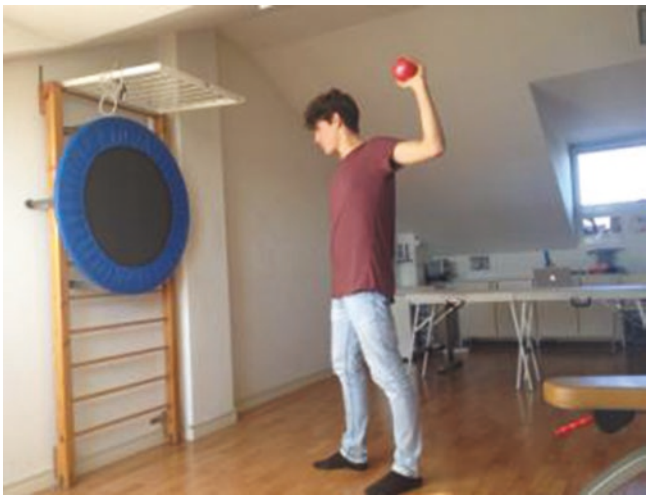


Fig. 11.48 An athlete performing sport-specific strengthening exercises with elastic and non-elastic resistance; the upper limb movement is trained avoiding all valgus or varus stress; core stability exercises enhance proprioception



Fig. 11.49 An athlete performing sport-specific strengthening exercises with elastic and non-elastic resistance; the upper limb movement is trained avoiding all valgus or varus stress; core stability exercises enhance proprioception



Fig. 11.50 Training of basketball throwing motion at low speed avoiding varus and valgus stress



Fig. 11.51 Training of basketball throwing motion at low speed avoiding varus and valgus stress

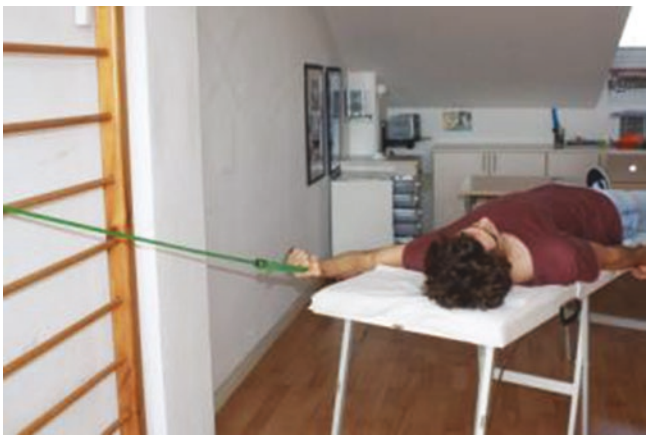


Fig. 11.52 Gravity-assisted elastic resistance exercises for the various phases of throwing



Fig. 11.53 Gravity-assisted elastic resistance exercises for the various phases of throwing



Fig. 11.54 Strengthening exercise for the epicondylar muscle with core stability exercise in seated position

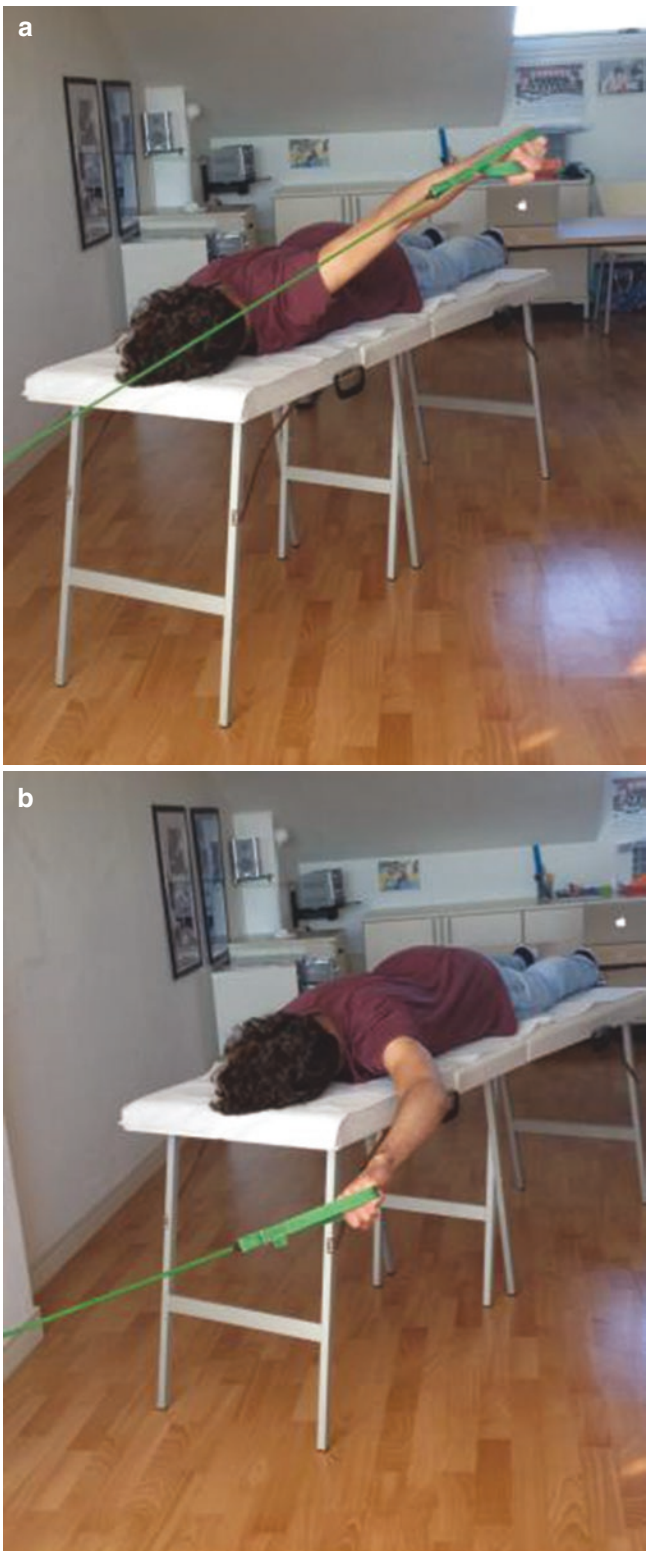


Fig. 11.55 (**a**, **b**) Elastic resistance exercises for the different phases of the throwing motion in prone decubitus against gravity

- subscapularis;
- biceps;
- triceps.

Exercises will use first elastic tubing and subsequently weights.

Training for the different sports is based on their specific motions and gestures. In some, the typical motion involves two different movement chains. The biomechanics of a boxing punch involves shoulder flexion and elbow extension, which belong to two different kinetic chains. This is why this movement, rather more than others, requires specific training and perfect coordination. In basketball, too, throwing to the basket involves shoulder flexion, elbow extension, and wrist flexion, and each of these movements needs to be addressed in the different stages of rehabilitation.

The main outcome measures used to assess these patients include:

Mayo Elbow Performance Score (MEPS).

Broberg-Morrey index.

Disabilities of the arm, shoulder, and hand (DASH) score.

VAS for pain.

The above data and considerations regard lateral and medial posterior instability. A similar rehabilitation process, involving similar timing and stages, can be applied to manage simple anterior instability as follows: (a) here, too, drainage of the UTO is critical as in the case of posterior dislocation; (b) full extension should be avoided in the first 30 days post-trauma; (c) the goal should be full ROM recovery, and (d) emphasis should be placed on strengthening the elbow flexors (humeral biceps) to achieve anterior joint stabilization.

Goals and outcomes clearly depend on the complexity of the dislocation and on patient characteristics. Each rehabilitation treatment should therefore be tailored to the individual patient: a personalized program that takes into account published guidelines and the specificities of the patient and of their injury has the potential to allow their successful return to daily and sports activities.

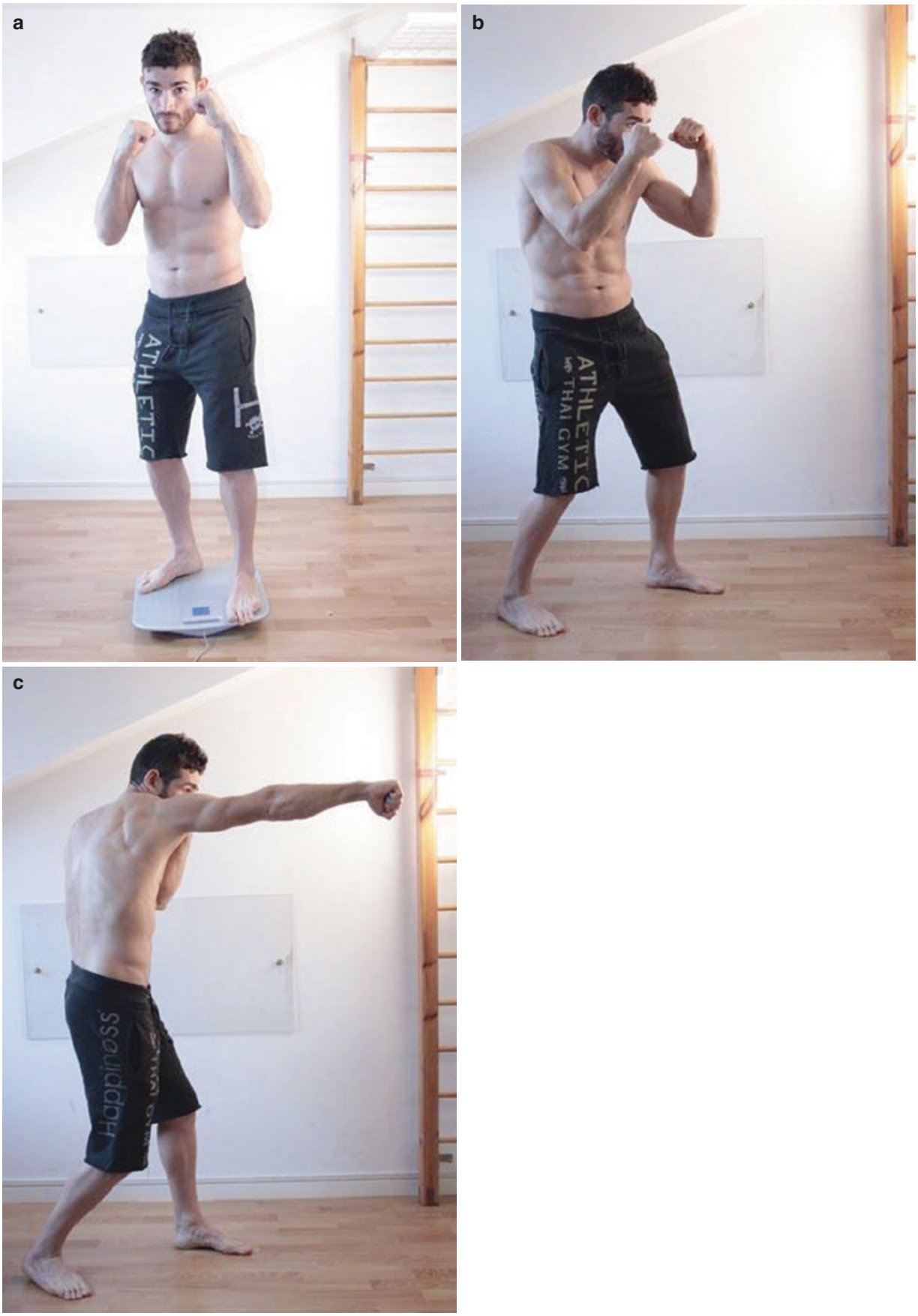
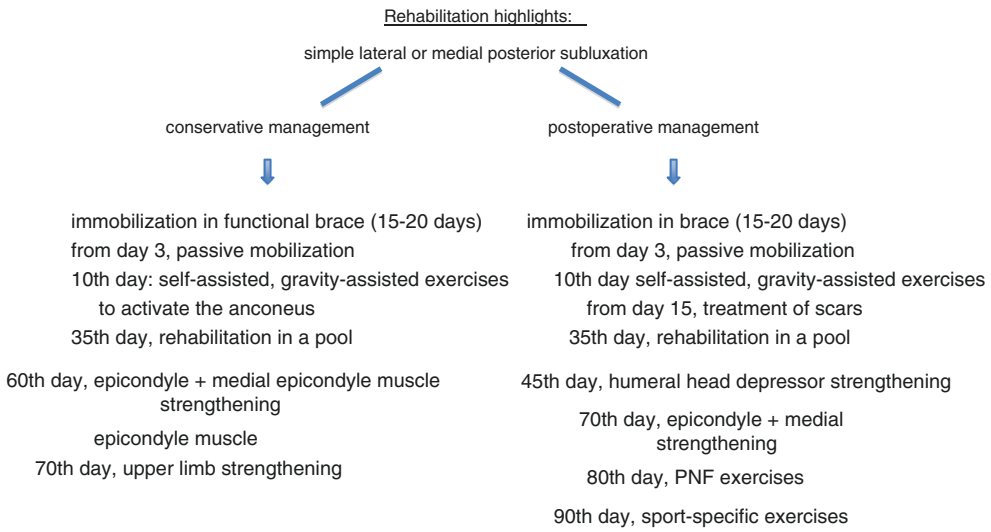


Fig. 11.56 (**a**, **b**, **c**) Exercises for boxing motion recovery with training of core stability (Carli Di Giacomo)



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Complex Elbow Instability: Treatment and Rehabilitation

12

Giuseppe Giannicola, David Polimanti, and Marco Scacchi

12.1 Introduction

Complex elbow instability (CEI) is due to osteoarticular fractures associated with capsule-ligament tears and muscle-tendinous lesions, which lead to a loss of elbow stability. These injuries represent a challenge even for expert orthopaedic surgeons, with unsatisfactory results still being reported in 33–44% of patients and revision surgery being required in 26–55% of patients (Biyani et al. 2000; Chen et al. 2014; Jupiter et al. 1991; Konrad and Kundel 2007; Morrey 1998, 2009; Ring et al. 1998; Ring and Jupiter 2002).

The stability of the elbow joint is provided by primary stabilizer structures, including bony constraints (i.e. coronoid and olecranon processes and humeral trochlea) and soft tissue constraints (i.e. lateral and medial collateral ligaments), both of which contribute equally to elbow stability (Beingessner et al. 2007; Closkey et al. 2000; Deutch et al. 2003; Hull et al. 2005; Morrey and An 1983, 2005; Morrey et al. 1991; O'Driscoll et al. 2001). In general, elbow instability occurs when two, or more than two, of these anatomical structures are injured. The degree of instability, as well as the complexity of the surgical treatment, may further increase when associated injuries of the secondary elbow stabilizer (i.e. radiocapitellar joint, anterior and posterior joint capsule, epitrochlear/epicondyle muscle-tendinous units and muscles passing over the elbow) are present (Deutch et al. 2003; Morrey and An 2005; Park and Ahmad 2004; Sabo et al. 2010; Seiber et al. 2009; Shukla et al. 2015).

Complex elbow instability may be detected radiographically when the elbow is completely dislocated; since it often also occurs without dislocation or with a slight joint malalignment on the coronal or sagittal planes, the complexity of the injury may easily be overlooked. In such cases, the injury is likely to be treated inadequately, ultimately yielding poor results. Indeed, one of the main causes of surgical failure is an inaccurate preoperative diagnosis, with additional lesions escaping detection (Chen et al. 2014; Giannicola et al. 2010a; Morrey 2009; Ring and Jupiter 2002; Wyrick et al. 2015).

In this chapter, we analyse the management of each of the possible patterns of complex elbow instability on the basis of a review of the literature and of our surgical experience, highlighting the possible guidelines for surgical treatment.

12.1.1 Diagnosis

CEI is usually associated with low-energy trauma. The most common mechanism of elbow fracture-dislocation is a fall onto the outstretched hand or a direct trauma at the elbow. Severe elbow pain, ecchymosis, swelling and deformity are usually present. The clinical examination should include the ipsilateral wrist and shoulder joints since concomitant injuries are present in almost 20% of patients (Sotereanos et al. 2007). A careful neurovascular examination ought to be performed before and after closed reduction, even though neurovascular injuries are rare in low-energy traumas.

Two-dimensional X-ray images (anteroposterior and lateral view) should be taken before and after repositioning manoeuvers. Closed reduction, in patients with minor bone injuries (i.e. terrible triad, radial head fracture and dislocation, coronoid fracture and dislocation) should be performed under general anaesthesia to avoid causing further pain and damage. By contrast, in patients with severe bone injuries, such as transolecranon and Monteggia-like fracture-dislocations, only a provisional fracture alignment followed by cast immobilization should be performed in the emergency room.

A computed tomography scan with 2D-3D reconstructions is mandatory in all cases to assess the extension and severity of bone injuries, whereas a fluoroscopy examination is essential for the evaluation of soft tissue constraints. The severity of ligament lesions and of residual elbow stability is usually assessed shortly before surgery. The patient's arm should be

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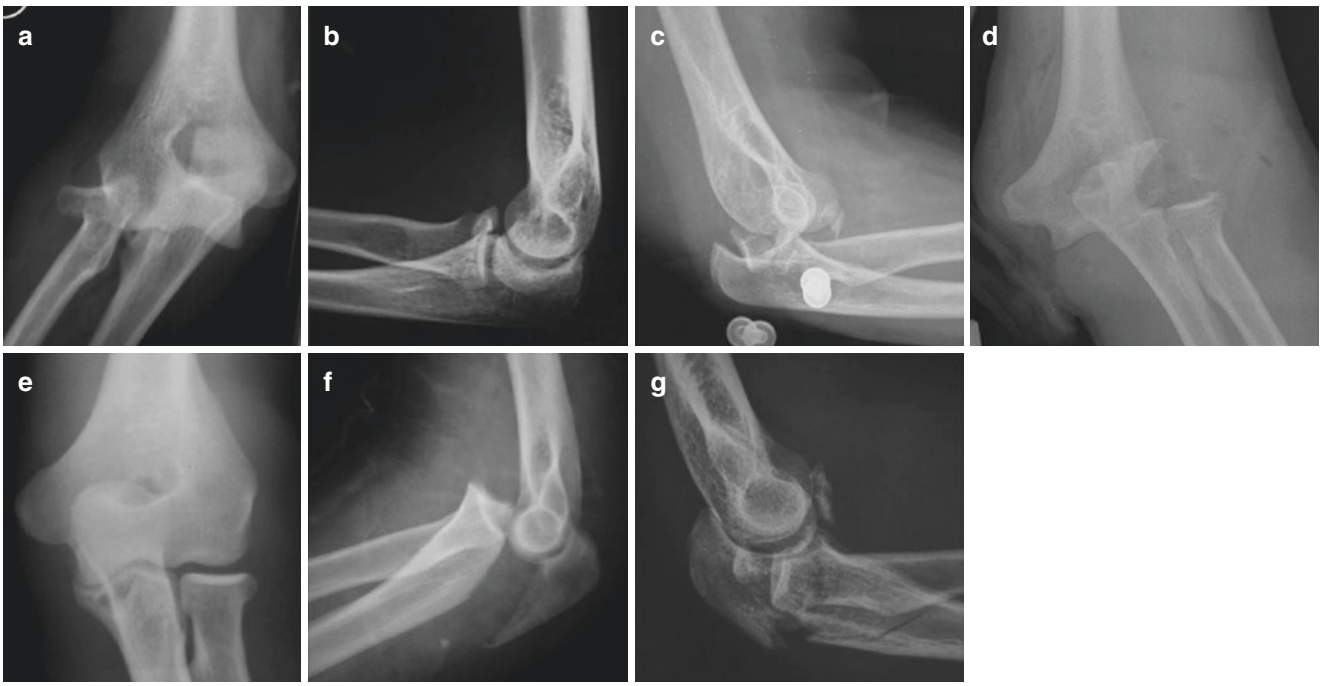


Fig. 12.1 X-ray images of complex elbow instability patterns. Posterolateral rotatory instability: (**a**) elbow dislocation with radial head fracture; (**b**) anterior coronoid fracture with lateral collateral ligament lesion; (**c**) terrible triad injury; (**d**) elbow dislocation with humeral shear fracture. Varus postero-medial rotatory instability: (**e**) anteromedial coronoid fracture with lateral collateral ligament lesion. Axial load injury and other unclear mechanisms of injury: transolecranon fracture-dislocations (**f**) and Monteggia-like lesions (**g**)

positioned under the radiograph intensifier, and the ability to maintain concentric reduction during flexion-extension in varying degrees of forearm rotation should be assessed; elbow joints should also be examined during valgus and varus stress tests at flexion angles of 0°–30°; the pivot shift test may also shed important information regarding LCL.

Several CEI patterns have been identified in recent decades. Currently CEI includes the following fracture-dislocations: (1) radial head fractures associated with lateral and medial collateral ligament lesion; (2) coronoid fractures with a lateral collateral ligament lesion; (3) terrible triad; (4) fracture-dislocations of the proximal ulna and radius, also referred to as transolecranon fracture-dislocations and Monteggia-like lesions; and (5) humeral shear fractures associated with lateral and medial collateral ligament lesions (Fig. 12.1).

12.1.2 General Principles of Treatment

Although the CEI patient presents with a range of clinical and radiographic patterns, the principles and the surgical steps involved in the treatment of these injuries are shared, which thus allows a single therapeutic algorithm to be defined.

First of all, CEI holds no place for conservative treatments except in rare cases in which the elbow, after the manual reduction, appears stable and the associated fractures are simple and not displaced (Chan et al. 2014; Guitton and Ring 2010). In the majority of cases, the elbow is unstable and the fractures are displaced, thus rendering surgical treatment indispensable. The primary aims of surgery are (1) to restore the anatomy of the elbow joint by means of stable osteosynthesis, (2) to obtain a stable elbow by means of reliable ligament reconstruction and (3) to allow early rehabilitation, which has been shown to be the key factor for a successful outcome.

12.1.2.1 Surgical Approaches

There are several ways to approach the elbow surgically. The approaches can be based on either a lateral incision, with a supplemental medial incision when indicated, or a global posterior incision. According to recent reports in the literature, the posterior skin incision appears to be the most useful, affording access to both the lateral and medial compartments of the elbow. However, this incision also creates large skin flaps, which may give rise to dead-space hematoma or wound edge necrosis, though these complications are uncommon in many authors' experiences (Cheung and Steinmann 2009; Dowdy et al. 1995; Giannicola et al. 2010a; Morrey 2009; Ring and Jupiter 2002; Wyrick et al. 2015).

As regards deep surgical exposure, various approaches to the radio-humeral articulation have been described by different authors (Boyd 1947; Gordon 1967; Kaplan 1941; Kocher

1911). Kocher's interval, which is the most frequent of these approaches, provides excellent exposure in radial head and capitellum fractures and associated soft tissue lesions, such as LCL complex tears. This approach enters the joint through the interval of the anconeus and extensor carpi ulnaris, thus protecting the deep radial nerve. Furthermore, the Kocher approach has the advantage of being extensile, affording a full complement of surgical options as the exposure is extended.

As regards deep medial approaches, the two predominant approaches described are the Hotchkiss 'over the top' and the flexor carpi ulnaris-splitting approaches (Kasparyan and Hotchkiss 1997), with the former being the more common. By splitting the flexor-pronator musculature ahead of the flexor carpi ulnaris and elevating its anterior portion laterally, the Hotchkiss approach provides a good exposure of MCL and coronoid process lesions. Alternatively, in cases in which anteromedial larger fragments of the coronoid are present, the entire flexor-pronator mass may be elevated from the postero-medial border of the ulna. Attention should be paid to avoid causing damage to the ulnar nerve, which should be identified and isolated prior to these manoeuvers.

A direct posterior exposure is adopted in ulnar shaft fractures, in which the ulnar shaft is visualized by widening the extensor and flexor muscles from the subcutaneous posterior border of the ulna.

12.1.2.2 Surgical Principles

The same surgical principles of treatment should be followed in all CEI patterns. We have identified a *rule of seven principles* whose aims are the following:

1. To restore the main joint of the elbow, i.e. the ulno-humeral joint. This is achieved by means of the anatomical reduction and stable osteosynthesis of the coronoid and olecranon fractures.
2. The radio-humeral joint should always be preserved on account of its role as a secondary stabilizer of the elbow; radial head or humeral shear fractures must be fixed or replaced, particularly if the ulno-humeral joint and medial collateral ligament have been compromised; resection of the radial head is very rarely indicated in CEI.
3. Attention should be paid to the recovery of bone length, alignment and rotation in cases of ulnar and radial shaft fractures to restore the functions of the forearm, particularly of its rotations.
4. The LCL complex must be repaired in all cases after osteosynthesis of fractures in order to recover elbow stability. Intraoperative testing under fluoroscopy should show a stable and congruent elbow; regarding this issue, some authors have suggested that stability is adequate when the elbow can be extended to 45° without complete dislocation or joint widening on the sagittal (negative drop sign) or frontal planes (negative wedge sign) (Morrey 1998). Other authors, including our group, feel that confidence in the elbow's stability is provided by the possibility to extend the elbow almost completely without any instability (Ring et al. 1998).
5. The MCL should be repaired if persistent instability is observed after LCL repair and in cases in which the medial compartment is exposed for other reasons (e.g. coronoid ORIF).
6. A hinged external fixator should be applied if the elbow continues to be unstable after MCL repair and in cases in which osteosynthesis is unstable or ligament reconstruction is tenuous. This device allows early mobilization of the elbow, ensures ligament healing in physiological tension and protects the osteosynthesis (Nielsen et al. 2002; Tan et al. 2005).
7. All the surgical steps performed should be re-evaluated if congruent ulno-humeral and radio-humeral joints have not been achieved by the end of surgery.

12.1.3 Soft Tissue Constraint Injuries in Complex Elbow Instability: Pathoanatomy, Classification, Prevalence and Treatment

Soft tissue constraint injuries are a consistent finding in all CEI patterns (Giannicola et al. 2012a; McKee et al. 2003; Morrey 1998, 2009; Ring and Jupiter 2002); if these lesions are not recognized and treated adequately, postoperative elbow instability is likely to develop, and disappointing long-term clinical results are to be expected (Morrey 1998, 2009; Ring and Jupiter 2002; Wyrick et al. 2015). We have dedicated a separate paragraph to this topic to highlight its clinical relevance.

A comprehensive classification of ligament, posterolateral capsule (PLC) and muscle-tendinous injuries in CEI has recently been proposed (Fig. 12.2); this classification was based on the intraoperative visualization of 47 consecutive cases of CEI (Giannicola et al. 2012b). Ligament injuries were classified as simple or complex lesions, depending on whether the ligament was damaged in only one portion or in two to three portions, which include its proximal portion (type P: up to 1 cm from its humeral origin), middle portion (type M: more than 1 cm distal to its humeral origin and more than 1 cm proximal to its ulnar insertion) and distal portion (type D: up to 1 cm from its ulnar insertion). The ligament lesion associated with avulsed bone fragments larger than 5 mm was recorded, with the acronym BF (bone fragment) being added to the type of lesion. PLC injuries were classified as small or large in the presence of capsular avulsions from the posterolateral surface of the capitulum humeri that were respectively smaller or larger than 1 cm.

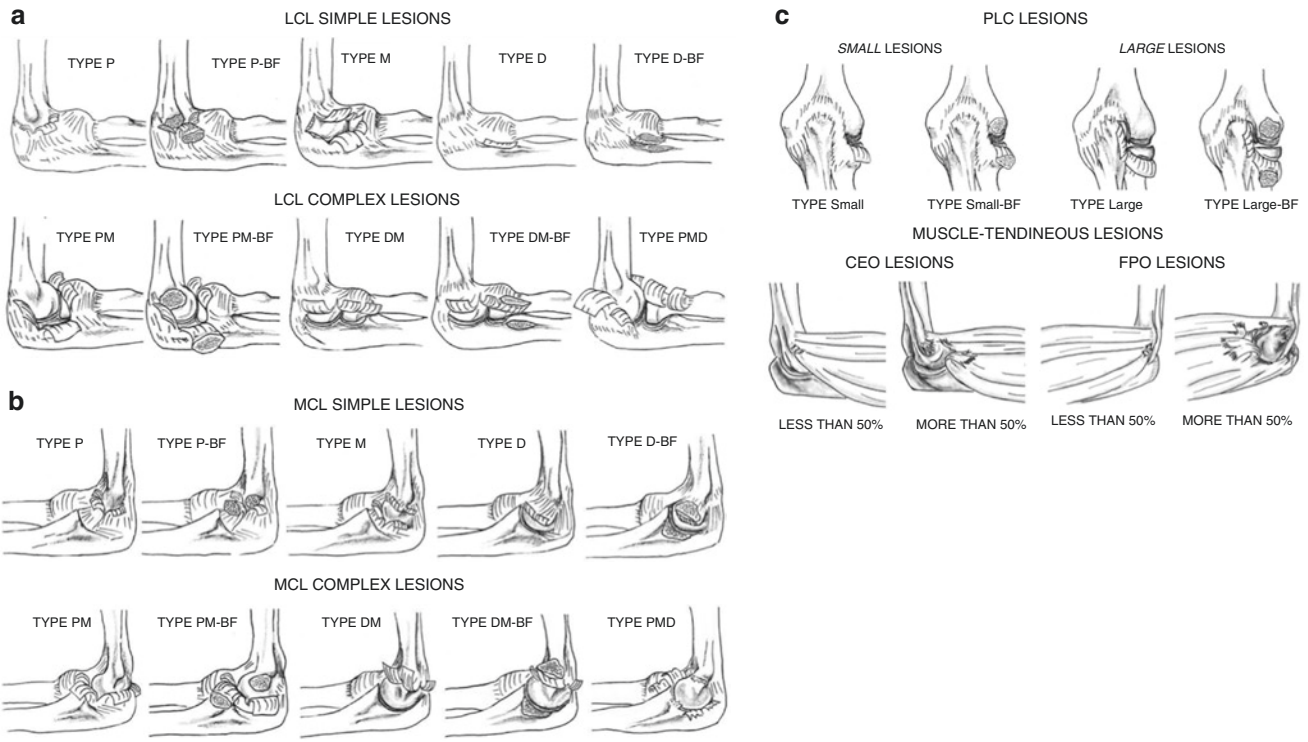


Fig. 12.2 Classification of soft tissue constraint injuries of the elbow: lateral collateral ligament lesions (LCL) (**a**), medial collateral ligament lesions (MCL) (**b**), posterolateral capsule (PLC) and muscle-tendinous injuries (**c**) in complex elbow instability (From: Giannicola G, Polimanti D, Sacchetti FM et al. (2012) Soft tissue constraint injuries in complex elbow instability: prevalence, pathoanatomy, and classification. Orthopedics. 35(12):e1738–45)

Lesions of the common extensor muscle origin (CEO) and flexor-pronator muscle origin (FPO) were defined as lesions in which the lack of tendon continuity exceeded 50%, as described by McKee (McKee et al. 2003).

LCL was the most frequently injured soft tissue constraint in CEI (96%), with a complex lesion being observed in the majority of cases (57%). Medial collateral ligament and PLC tears were observed in approximately 45% and 66% of cases, respectively. PLC lesions were always associated with proximal LCL avulsion, which was invariably combined with anconeus humeral detachment in large tears. CEO injuries were detected in 21% of cases, while FPO tears were observed in two out of six cases which were assessed intraoperatively for LCM or for coronoid reconstruction purposes (Table 12.1).

In a recent study, Giannicola et al. (Giannicola et al. 2012a) proposed a detailed surgical technique to repair each lesion pattern. Type P and type D lesions of the LCL and MCL were treated by means of a double-wire suture anchor positioned perpendicular to the ligament origin or insertion and by using two modified Mason-Allen stitches. When a bone fragment was associated with proximal or distal avulsion (type P-BF and type D-BF), the lesion was fixed with one to two suture anchors placed at the fracture site, with the suture wires passing through or around the bone fragment depending on its dimension and shape. Type M (midsubstance) lesions were repaired by means of side-to-side cross sutures. Complex lesions were repaired using both the aforementioned techniques. Type PMD lesions, in which the lateral collateral ligament was entirely torn and could not be repaired, were also treated with a hinged external fixator after placement of the sutures.

Several studies recently published in the literature have highlighted the relevance of secondary soft tissue stabilizers (i.e. PLC, CEO, FPO, anconeus muscle, flexor elbow muscles, triceps muscle) to elbow stability, especially in the presence of primary stabilizer deficiency (including that of triceps instability). The authors of this chapter consequently believe that such injuries should also be treated in CEI. The lateral collateral ligament reconstruction was therefore combined with repair of small posterolateral capsule lesions using the posterior wire of the suture anchor for lateral collateral ligament reinsertion. Large PLC tears, which are always associated with an anconeus detachment, were repaired using another anchor placed perpendicular to the non-articular posterior surface of the capitulum humeri. Lastly, CEO and FPO lesions were repaired similarly to ligament tears. Figure 12.3 shows the surgical technique of ligament reconstruction.

Table 12.1 Prevalence of soft tissue constraint injuries in each pattern of CEI

Complex elbow instability patterns	Type P	Type M	Type D	Type PM	Type DM	Type PMD	CEO	MCL[a]	PMC small	PLC large
Terrible triad (n = 13)	1	1	1-BF	8	–	2	7	8	4	5
Radial head fracture-dislocation (n = 6)	1	2	–	3	–	–	2	2	3	1-BF
Monteggia-like lesion (n = 17)	5 (1-BF)	1	–	7	2	–	–	5	11	1
Distal humerus shear fracture-dislocation (n = 6)	1	2	–	2	1	–	–	4	3	–
Transolecranon fracture-dislocation (n = 2)	–	–	–	–	–	–	–	–	–	–
Coronoid fracture-dislocation (n = 3)	1-BF	–	–	2	–	–	1	2	2	1
Total	9	6	1	22	3	2	10	21	23	8

[a]MCL tear was indirectly evaluated with intraoperative fluoroscopy

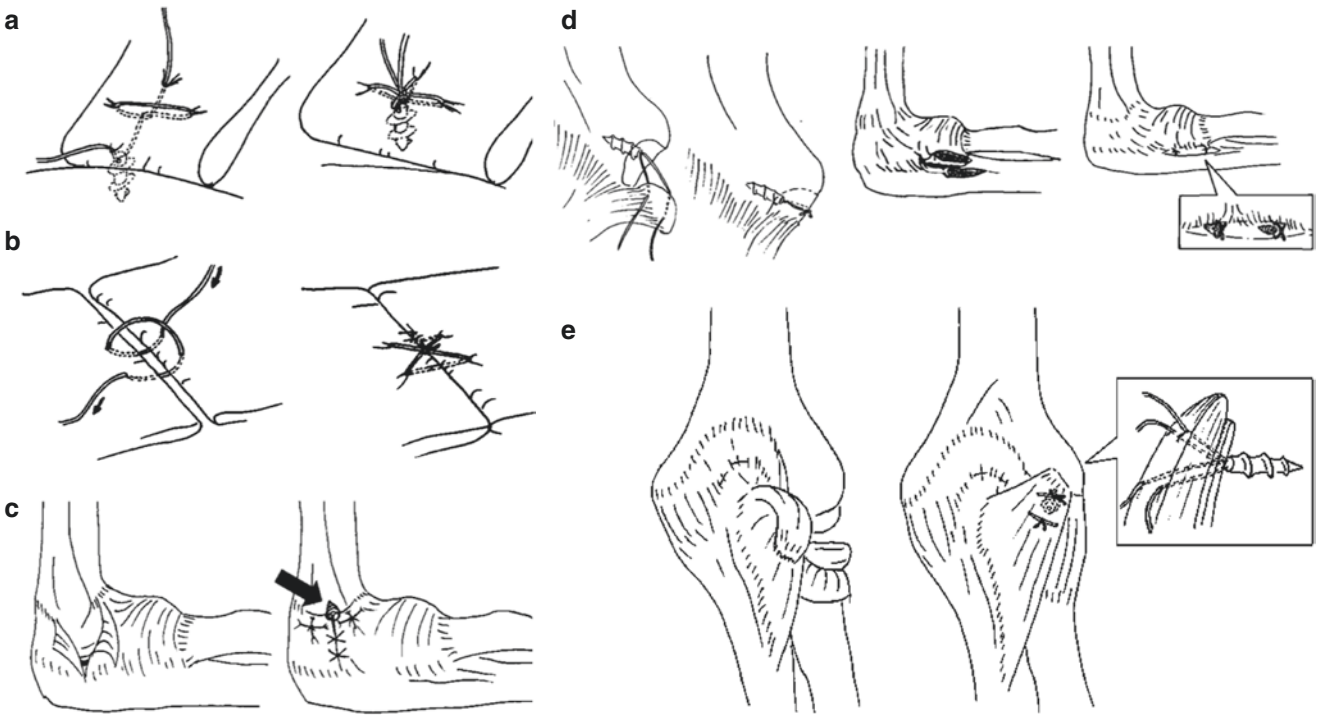


Fig. 12.3 Surgical techniques of ligament reconstruction. (**a**) Modified Mason-Allen stitch performed to repair type P (proximal) and D (distal) ligament lesions and tendon detachment. (**b**) Side-to-side cross suture performed to repair type M (middle-zone) ligament and muscle lesions. (**c**) Surgical techniques used to repair complex lesions: the lesion is first reduced into a simple lesion using side-to-side cross sutures to repair the midsubstance tear; a suture anchor (*arrow*) is then positioned perpendicular to the tubercle of the lateral epicondyle to reinsert the ligament with two modified Mason-Allen stitches. (**d**) Surgical techniques used to repair ligamentous lesions associated with bone fragment (type BF). One or two suture anchors were placed on the fracture site with suture wires passed through (*left*) or around (*right*) the bone fragment depending on its dimensions and shapes. (**e**) Posterolateral capsule large lesions associated with an anconeus humeral detachment (*left*). A suture anchor was placed on the non-articular posterolateral surface of the capitulum humeri; suture wires were then passed through the capsular and the anconeus tendon, and two single stitches were positioned to close the posterolateral corner (*right*) (From: Giannicola G, Polimanti D, Sacchetti FM et al. (2012) Soft tissue constraint injuries in complex elbow instability: surgical techniques and clinical outcomes. Orthopedics. 35(12):e1746–53)

12.2 Complex Elbow Instability Patterns

12.2.1 Radial Head Fractures with Associated Lateral and Medial Collateral Ligament Lesions

Radial head fractures (RHF) are the most frequent bone elbow injury in adults, accounting for approximately 33% of all elbow fractures (Herbertsson et al. 2004); it is important to stress that isolated displaced fractures occur in fewer than 5% of patients, with concomitant injuries, including other fractures, elbow dislocation or collateral ligament tears being present in all other cases (Morrey 1993; Van Riet et al. 2005b). Radial head fractures associated with ligament lesions are common and usually due to a combination of valgus and axial loads being placed on a supinated and extended elbow joint (i.e. posterolateral rotatory instability).

The surgeon should always suspect associated ligament lesions, particularly in displaced and comminuted fractures (Mason types 2–3). A thorough clinical examination is essential to identify any associated lesions. For instance, the presence of medial pain and ecchymosis may suggest a MCL tear, which may be confirmed by means of fluoroscopy, whereas posterolateral pain, pivot shift and varus stress tests are useful in lateral collateral ligament lesions.

The Mason-Hotchkiss classification (Hotchkiss 1997) is a useful tool when planning surgery of RH fractures, even in CEI. Type 1 fractures are defined as non-displaced fractures or minimally displaced marginal lip fractures (<2 mm displacement) that do not block motion and can be treated non-operatively. Type 2 fractures (partial head) are displaced fractures (usually >2 mm) that may be associated with a mechanical block to motion or are incongruent but are not severely comminuted. Type 2 fractures are often amenable to open reduction and internal fixation. Finally, type 3 fractures (whole head) are comminuted fractures that often cannot be repaired and consequently need to be treated by means of radial head arthroplasty (RHA). Osteosynthesis in this type of fracture is often troublesome and may require mini-plates.

Despite numerous clinical studies and advances in technology, controversy still exists regarding the indications for open reduction and internal fixation (ORIF) as opposed to conservative treatment in some fractures in which displacement is slight. However, a recent biomechanical study showed that radial head fractures that are depressed 2 mm or angulated 30° may result in an 80% loss of concavity-compression stability of the radiocapitellar joint; the anatomical repair of such fractures should therefore be considered to prevent elbow instability (Shukla et al. 2012).

Similarly, disagreement persists regarding the indications for ORIF versus RHA for comminuted radial head fractures. Currently, the indications for RHA are (1) comminuted fractures involving the whole head in which satisfactory reduction and stable fixation cannot be achieved, (2) partial head fractures involving more than 30% of the articular rim of the radial head that cannot be reconstructed and (3) fractures with more than three fragments (Fowler and Goitz 2013).

Al Burdeni et al. (Al-Burdeni et al. 2015) claimed that there is no significant difference between RHA and ORIF in pluri-fragmentary and comminuted radial head fractures, whereas others believe that the RHA is a better surgical solution in such fractures, particularly in patients over 65 years of age (Li and Chen 2014; Liu et al. 2015; Ruan et al. 2009).

The osteosynthesis of partial head fractures can be performed through the Kocher interval with mini-fragment screws or headless screws, while precontoured mini-plates can be used when the fracture involves the whole radial neck and more stability is required; in such cases, the positioning of the plate in the non-articular portion of the radial head—the so-called safe zone—is essential to avoid hardware impingement during forearm rotation. In cases with radial neck bone deficiency, the bone may be augmented using autologous chips taken from the lateral column of the distal humerus.

Radial head excision is rarely indicated in CEI because it increases elbow instability. The radial head is widely known to provide approximately 30% of the resistance to valgus stress when the MCL is intact, though this percentage increases markedly when the ligament is injured (Morrey et al. 1991; Søjbjerg et al. 1987). The radial head also provides an anterior buttress to posterior elbow dislocation (Schneeberger et al. 2004; Shukla et al. 2012) when the elbow is flexed, and it is a primary stabilizer in forearm longitudinal stability (Morrey 1998). Several studies have demonstrated the association between radial head excision and certain complications, such as chronic valgus or longitudinal instability, ulno-humeral osteoarthritis, increased carrying angle and ulnar neuropathy (Herbertsson et al. 2004; Ikeda et al. 2005; Lindenhovius et al. 2007; Morrey et al. 1979; Pilato et al. 2004).

As mentioned above, the soft tissue constraint lesions of the lateral compartment must be repaired in all patients after radial head osteosynthesis or replacement, while the LCM should be repaired in selected cases. After surgery has ended, elbow stability should be tested under fluoroscopy.

Little information is available on the clinical results of treatment of acute posterolateral instability of the elbow associated with radial head fractures alone; indeed, most existing reports retrospectively analysed heterogeneous case series of CEI in which this pattern is present in few cases (Giannicola et al. 2014; Wang and Beredjiklian 2015). The results of studies that focused on radial head fractures alone

were instead unclear owing to the fact that no distinction was made between Mason type 4 fractures and other types of fractures. Furthermore, this pattern of CEI is frequently underdiagnosed and confused with simple radial head fractures. In a recent study, Giannicola et al. observed this pattern of CEI in 5 out of 78 patients with CEI and achieved satisfactory functional results in all cases after surgical treatment (Fig. 12.4) (Giannicola et al. 2014).



Fig. 12.4 Preoperative anteroposterior (**a**) and lateral (**b**) radiographs of radial head fracture associated with lateral and medial collateral ligament lesion. Intraoperative positive valgus (**c**) and varus (**d**) stress test. The patient presented a Mason III radial head fracture associated with a type DM LCL lesion and a large PLC injury with anconeus detachment. He was treated with radial head replacement, LCL and PLC reconstruction with suture anchors. Postoperative anteroposterior (**e**) and lateral (**f**) radiographs

12.2.2 Coronoid Fractures and Lateral Collateral Ligament Lesions

The coronoid process is one of the main elbow constraints providing ulno-humeral joint stability. Coronoid fractures are rare, being reported in 2–15% of patients with elbow dislocations. They rarely occur in isolation and are most often associated with other bony and soft tissue injuries around the elbow (Budoff 2012; Manidakis et al. 2012; Steinmann 2008; Wells and Ablove 2008). Several authors have suggested that specific types of coronoid fractures are closely associated with specific CEI patterns (Doornberg and Ring 2004; O'Driscoll et al. 2003). These observations are consistent with a recent computed tomography study (Mellema et al. 2015) that confirmed the strong association of small anterior transverse fractures with posterolateral rotatory instability, as in terrible triad (TT) injuries, whereas large basilar coronoid fractures are associated with anterior/posterior transolecranon fracture-dislocation; lastly, anteromedial facet (AMF) fractures are correlated with varus postero-medial rotational instability injuries.

Thus, two main mechanisms of injury underlie isolated coronoid fractures associated with elbow instability: (1) posterolateral rotatory instability and (2) the varus postero-medial rotatory instability. The first mechanism is responsible for small anterior coronoid fracture and is the same as that involved in TT injuries. The second mechanism, which was defined more recently, is caused by a combination of varus and axial load on an elbow joint in pronated position (Sanchez-Sotelo et al. 2006). The coronoid AMF protrudes medially from the ulna metaphysis and is vulnerable to varus stress trauma because approximately 60% of the facet is not supported by the ulnar metaphysis (Doornberg and Ring 2006). If the varus injury force continues, the lateral collateral ligament will fail, and an elbow subluxation or dislocation may occur (Regan and Morrey 1989; Ring 2006).

Since posterolateral instability alone was believed to occur and thus described in earlier studies on the elbow, the classification proposed by Morrey focused on fractures in the anterior section of the process; indeed, Morrey's classification (Morrey 1998) was based on the radiographic examination of these fractures on the sagittal plane. In 2003, O'Driscoll et al. introduced a new classification system, based on the anatomical location and size of the fractured fragment assessed by CT, which stressed the important contribution made by AMF fractures to reduced stability of the elbow. Briefly, the coronoid fracture can involve the tip (type 1), the anteromedial facet (type 2) or the base (type 3). These main types are further divided into subtypes according to the severity of coronoid involvement (O'Driscoll et al. 2003).

In cases of postero-medial instability, it is important to identify the type 2 fracture subtype: subtype 1 fractures involve the anteromedial rim, whereas subtype 2 fractures extend as far as the tip; subtype 3 fractures involve the anteromedial rim and the entire sublime tubercle, either with or without involvement of the tip of the coronoid. As regards type 2 fractures, it should be borne in mind that an untreated AMF fracture, even if small, may lead to varus postero-medial instability because of a concomitant LCL injury. The disrupted AMF allows the lateral ulno-humeral joint gap to open; this causes increased loading on the incongruent medial ulno-humeral joint under gravitational varus stress, which can ultimately result in early onset of medial-ulno-humeral arthritis (Budoff 2012; Manidakis et al. 2012; O'Driscoll et al. 2003).

Various techniques for coronoid fixation have been described, including transosseous sutures, K-wires, fine-threaded K-wires, screws and mini-plates, though the optimal treatment protocol and technique have not yet been established. The technique preferred by the authors of this chapter consists in using fine-threaded K-wires (FFS-Orthofix) (Giannicola et al. 2013a). FFSs are inserted through the posterior aspect of the ulna in such a way as to direct it towards the coronoid using a one-step fixation technique. Depending on the number and size of the fragments, a varying number of FFSs of different diameters (1.2, 1.6 or 2.2 mm) can be positioned to increase primary and rotational stability. We have shown that this technique provides easy, stable, minimally invasive and successful osteosynthesis (Fig. 12.5). Osteosynthesis with precontoured mini-plates is a valid alternative technique when wide medial exposure is required or in comminuted fractures, which increases the stability of the reconstruction and neutralizes biomechanical stress during early joint mobilization (Fig. 12.6).

In a biomechanical study on postero-medial instability, Pollock et al. (Pollock et al. 2009) recommended that small fragments (type 2-subtype 1) can be treated with LCL repair alone, whereas larger fragments (type 2-subtype 2 and type 2-subtype 3) require fixation of the fracture fragment in addition to LCL repair. Park et al. (Park et al. 2015) confirmed these recommendations in a clinical study, adding that if the elbow remains unstable after coronoid fixation and LCL repair, the surgeon should investigate a hidden MCL injury, particularly in subtype 2 fractures.

Therefore, restoration of the LCL is of greater importance than bone fixation in type 2-subtype 1 fractures because this injury may be related to posterior dislocation. In type 2-subtypes 2/3, anatomical reduction and fixation of the AMF and LCL repair are required because they act as a bone buttress that resists the varus force and provides joint congruency (Park et al. 2015; Pollock et al. 2009). In the presence of significant persistent instability and/or unstable ORIF of the coronoid process, a dynamic elbow fixator (DEF) should be considered (Wyrick et al. 2015).

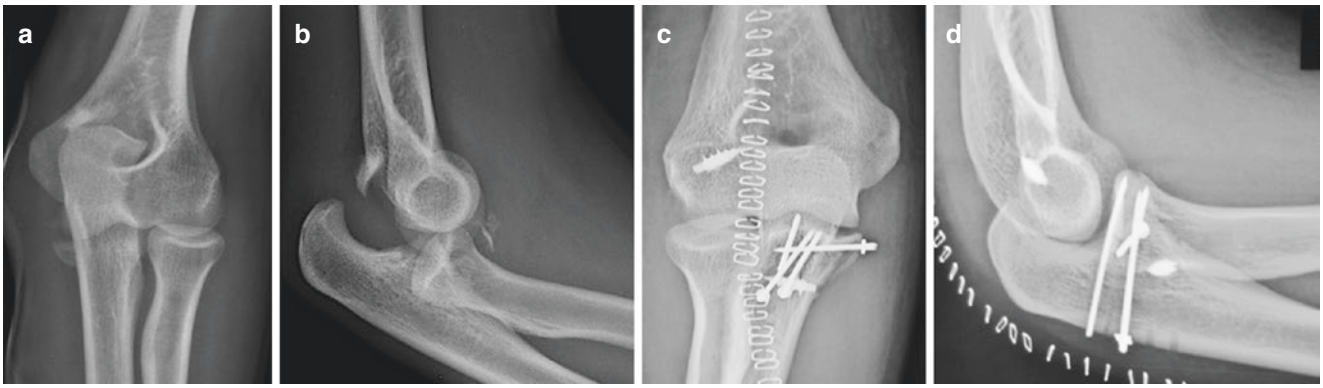


Fig. 12.5 Postero-medial rotational instability injury: Preoperative anteroposterior (**a**) and lateral (**b**) radiographs showing an anteromedial facet coronoid fracture associated with a posterior elbow dislocation. Postoperative anteroposterior (**c**) and lateral (**d**) radiographs showing coronoid fixation with threaded wires, LCL and MCL reconstruction with suture anchors

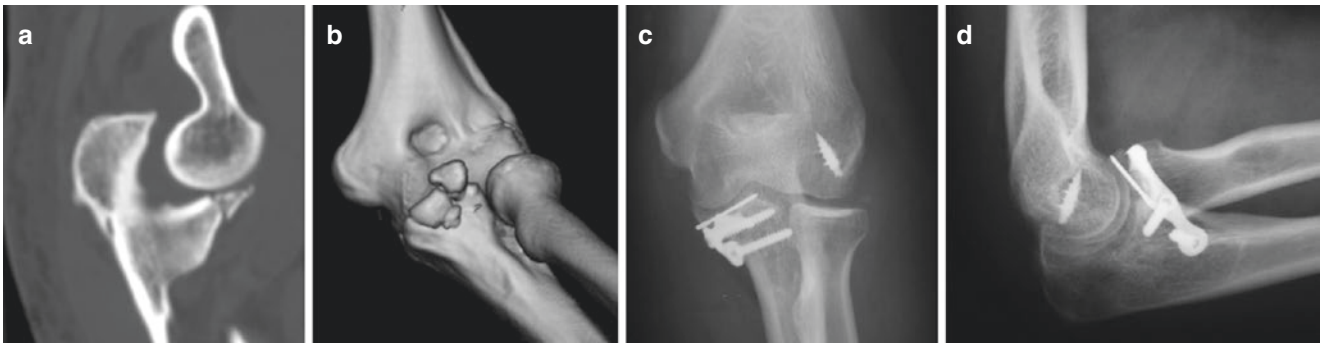


Fig. 12.6 Postero-medial rotational instability injury: Preoperative 2D (**a**) and 3D (**b**) computed tomography reconstruction showing an anteromedial facet coronoid fracture associated with elbow subluxation (**a**). Postoperative anteroposterior (**c**) and lateral (**d**) radiographs showing coronoid fixation with anteromedial plate and a threaded wire; LCL reconstruction was performed with a suture anchor

After surgery, the elbow should be protected from varus and gravitational stresses, with shoulder elevation in internal rotation being avoided by using a hinged brace for 6 weeks if necessary. Moreover, limited extension (30°–40°) may be advisable in the first 4 weeks to avoid placing mechanical loads on the anterior part of the coronoid.

The diagnostic and therapeutic principles regarding anterior coronoid fractures associated with posterolateral rotational instability are similar to those of the TT and are thus included in the following paragraph. However, it should be pointed out in this section that two different patterns of coronoid fracture associated with ligament lesions exist and that the underlying pathogenetic injury mechanism and the treatment of each pattern differ. It is important to identify which of these types of lesion the patient has sustained to be able to select the most appropriate surgical approach. In coronoid fractures due to posterolateral instability, in which the LCL is always torn, the deep lateral approach is performed first to reconstruct the coronoid ORIF and LCL. By contrast, the surgical exposure in postero-medial instability is selected according to the size of the coronoid fragment and the inconstant presence of the LCL lesion.

12.2.3 Terrible Triad

In 1996, Hotchkiss first clearly described a complex pattern of elbow fracture-dislocation characterized by a posterior dislocation associated with radial head and coronoid fractures, which he termed the ‘terrible triad of the elbow’ (Hotchkiss 1996). The mechanism that causes this injury is a valgus posterolateral rotatory load, resulting from an axial load combined with both valgus and supinating forces on the elbow. The compression and valgus forces cause the fracture of the anterior coronoid and radial head, while the pathological supination avulses the LCL; furthermore, an MCL tear is associated with other lesions in approximately 60% of cases (Giannicola et al. 2012a; McKee et al. 2003).

The TT is a serious injury that even an expert elbow surgeon will find challenging to treat and that may result in chronic instability, elbow stiffness, post-traumatic arthritis with loss of function and chronic pain (Chemama et al. 2010; Egol et al. 2007; Fitzgibbons et al. 2014; Forthman et al. 2007; Garrigues et al. 2011; Josefsson et al. 1989; Kälicke et al. 2007; Leigh and Ball 2012; Lindenhovius et al. 2008; Ring et al. 2002; Seijas et al. 2009; Tarassoli et al. 2013; Van

Riet et al. 2005a; Wang et al. 2010; Watters et al. 2014; Winter et al. 2009). The TT is the CEI pattern that has been investigated most and that has historically been associated with a poor prognosis (Broberg and Morrey 1987; Hotchkiss 1996; Josefsson et al. 1989; Regan and Morrey 1989; Ring et al. 2002; Terada et al. 2000).

Most of these fracture-dislocations were once treated conservatively, by means of closed reduction and cast immobilization, though this type of treatment generally failed (Josefsson et al. 1989; Terada et al. 2000). In the last two decades, the fact that the TT should be treated surgically in the majority of cases has become widely accepted, with nonoperative treatment being reserved for few selected cases (Chan et al. 2014; Guitton and Ring 2010; Mathew et al. 2009). Although an increased knowledge of primary and secondary elbow stabilizers and the use of more standardized treatments appear to have yielded more favourable and reproducible clinical outcomes in recent studies (Chemama et al. 2010; Fitzgibbons et al. 2014; Forthman et al. 2007; Jeong et al. 2010; Leigh and Ball 2012; Lindenhovius et al. 2008; Papatheodorou et al. 2014; Rodriguez-Martin et al. 2011; Watters et al. 2014; Zeiders and Patel 2008; Zhang et al. 2014), a high rate of complications and re-interventions persists (Chen et al. 2014).

The aim of TT treatment, which is the same as that of all patterns of CEI, is to restore the primary and secondary stabilizers of the elbow so as to obtain a stable joint and allow early rehabilitation. A posterior skin incision is usually performed to offer good exposure of both the medial and lateral compartments, especially in cases with MCL disruption. The radial head fracture is exposed through the Kocher interval, which widens the LCL lesion. Before radial head reconstruction or arthroplasty, coronoid osteosynthesis can be performed through a lateral approach after any radial fragments have been removed. The coronoid fracture is often a small type 1 Regan-Morrey fracture that can be treated simply by means of a transosseous suture (Fig. 12.7). If an isolated fragment that is large enough to be fixed is present, threaded K-wires or screws may prove useful (Fig. 12.8). Alternatively, the coronoid ORIF may be performed by adopting the medial approaches in cases of small radial head fractures in which coronoid fragment visualization is poor.

Some authors have suggested that small coronoid fractures do not require osteosynthesis (Chan et al. 2014; Mathew et al. 2009; Papatheodorou et al. 2014), though the need to synthesize small fragments is likely to depend on the humeral coverage angle of the greater sigmoid notch (GSN-ca) (Giannicola et al. 2015; Wadström et al. 1986). Indeed, the significant variability in the GSN-ca on the sagittal plane that emerged from a recent RMN anatomical study suggests that coronoid treatment should be personalized. In this regard, the ORIF of small coronoid fractures may be more indicated in GSNs with a low GSN-ca than in those with a higher GSN-ca (Giannicola et al. 2015; Wadström et al. 1986). The authors of this chapter believe that a coronoid ORIF should be performed whenever osteosynthesis is possible. After the coronoid ORIF has been performed, the radial head and ligaments should be treated as previously described in the general principles.

Chen et al. (Chen et al. 2014), who performed a meta-analysis of 312 cases, reported that functional outcomes



Fig. 12.7 Terrible triad injury. Postoperative X-rays showing radial head osteosynthesis, transosseous sutures of the coronoid tip (*arrows*), LCL, PLC and MCL reconstruction with suture anchors



Fig. 12.8 Terrible triad injury treated with (*1*) radial head osteosynthesis with low-profile locking plate, (*2*) coronoid osteosynthesis with transosseous sutures and two threaded wires and (*3*) LCL reconstruction with suture anchor: Preoperative three-dimensional (**a**) computed tomography reconstruction. Postoperative X-rays at 1 week (**b**) and 2 years (**c**) of follow-up

after surgery for the TT are generally satisfactory and that complications are common. Mean Mayo elbow performance scores ranged from 78 to 95. Mean Broberg-Morrey scores ranged from 76 to 90. Mean DASH scores ranged from 9 to 31. The proportion of patients who required a reoperation owing to complications ranged from 0 to 54.5% (mean 22.4%). Most of these complications were related to hardware fixation problems, joint stiffness, joint instability and ulnar neuropathy. The most common complications that did not require a reoperation were heterotopic ossification (12.5%) and arthrosis (11.2%). These results confirm that the treatment of the TT remains challenging and the complication rate significant.

12.2.4 Fracture-Dislocations of the Proximal Ulna and Radius: Monteggia-Like Lesions and Transolecranon Fracture-Dislocation

Fracture-dislocations of the proximal ulna and radius (FDUR) account for 2–5% of all elbow injuries (Eathiraju et al. 2007; Josten and Freitag 2009). The term 'fracture-dislocations of proximal ulna and radius' includes any ulnar fracture associated with an isolated elbow joint dislocation or multiple elbow joint dislocations (radio-humeral, ulno-humeral and proximal radio-ulnar joints); in order to be included in this definition, the whole ulna has to be damaged so as to distinguish this from other conditions, such as TT injuries, in which only a portion of the proximal ulna (i.e. the coronoid process or supinator crest) is fractured (Giannicola et al. 2011).

In 1814, Monteggia first described the fracture of the proximal ulna associated with anterior dislocation of the radial head (Monteggia 1814). However, until a few decades ago, the eponym 'Monteggia fractures' was also used to indicate further complex FDURs that were not originally included by Monteggia himself. These types of lesions usually consist of a combination of coronoid, olecranon, ulnar shaft and radial head injuries, i.e. most of the bone structures involved in elbow stability.

Although several FDUR classifications have been proposed over the years, none appears to be exhaustive and most are of little therapeutic or prognostic value (Boyd and Boals 1969; Bruce et al. 1974; Egol et al. 2005; Givon et al. 1997). Furthermore, as most of these classifications were drawn up a number of years ago, they do not take into account more recent knowledge on the functional anatomy of the elbow, including the complex interaction between bone and soft tissue constraints of the joint (Hotchkiss et al. 1989; Jupiter et al. 1991; Morrey et al. 1991; Pomianowski et al. 2001; Wadia et al. 2007).

A new comprehensive classification of fracture-dislocations of the proximal ulna and radius (PURCCS) was recently proposed (Giannicola et al. 2011) (Fig. 12.9). The aim of the classification is to identify definite anatomical lesions, referred to as 'main lesions', whose presence affects the prognosis and that require specific treatment. The main lesions include the following: (1) the type of ulnar fracture, including its location in relation to the insertion of the collateral ligaments and coronoid process (types 1–6), (2) the presence of a radio-humeral dislocation, (3) the presence of a proximal radio-ulnar dislocation, (4) the presence of radial fractures, (5) the presence of the distal radio-ulnar joint and interosseous membrane lesions and, lastly, (6) the presence of an ulno-humeral dislocation. The main lesions were labelled using an alphanumeric system. In this classification, any given FDUR pattern results from the association of at least two main lesions, including an ulnar fracture combined with an isolated dislocation or multiple dislocations of the elbow joints.

Since a missed diagnosis of soft tissue constraint injuries associated with the dislocation of the elbow and wrist joints was one of the most frequent causes of poor outcome in FDUR (Ahmad et al. 2007; Doornberg et al. 2007; Givon et al. 1997; Reckling 1982; Ring et al. 1998), this classification was specifically designed to take into account possible damage to the collateral ligaments that may occur in patients with these injuries; the lesions were therefore classified as type A and type B lesions. A type A lesion indicates the presence of a radio-humeral dislocation but no injury to the proximal radio-ulnar joint. Moreover, a type A lesion is usually associated with a type 1 ulnar fracture (olecranon fracture) and both bones in the forearm dislocate as a single unit. We distinguish between two possible directions of a radio-humeral joint dislocation: anterior (AI) and posterior (AII). A type AI lesion corresponds to the anterior transolecranon fracture-dislocation described by Biga and Thomine (Biga and Thomine 1974), whereas a type AII lesion corresponds to the rare posterior transolecranon fracture-dislocation described by Marotte et al. (Marotte et al. 1982). The LCL and MCL may occasionally be injured, whereas the annular and quadrate ligaments are consistently intact. The type A lesion is mainly a bone injury.

A type B lesion is a radio-humeral dislocation that is associated with a proximal radio-ulnar joint dislocation. This dislocation can be anterior (BI), lateral (BII) or posterior (BIII). The annular and quadrate ligaments are always injured, and a complex lesion of the LCL is often associated. Type B lesions identify the typical joint damage observed in the Monteggia fracture-dislocation described by Bado (2). The dislocations in these cases are frequently combined with a type 2 ulnar fracture (shaft fracture), with the association of a proximal radial fracture also being possible.

Therefore, in PURCCS the isolated dislocations of the radio-humeral joint (type A) are distinguished from those associated with a proximal radio-ulnar joint dislocation (type B) insofar as the former do not require any soft tissue

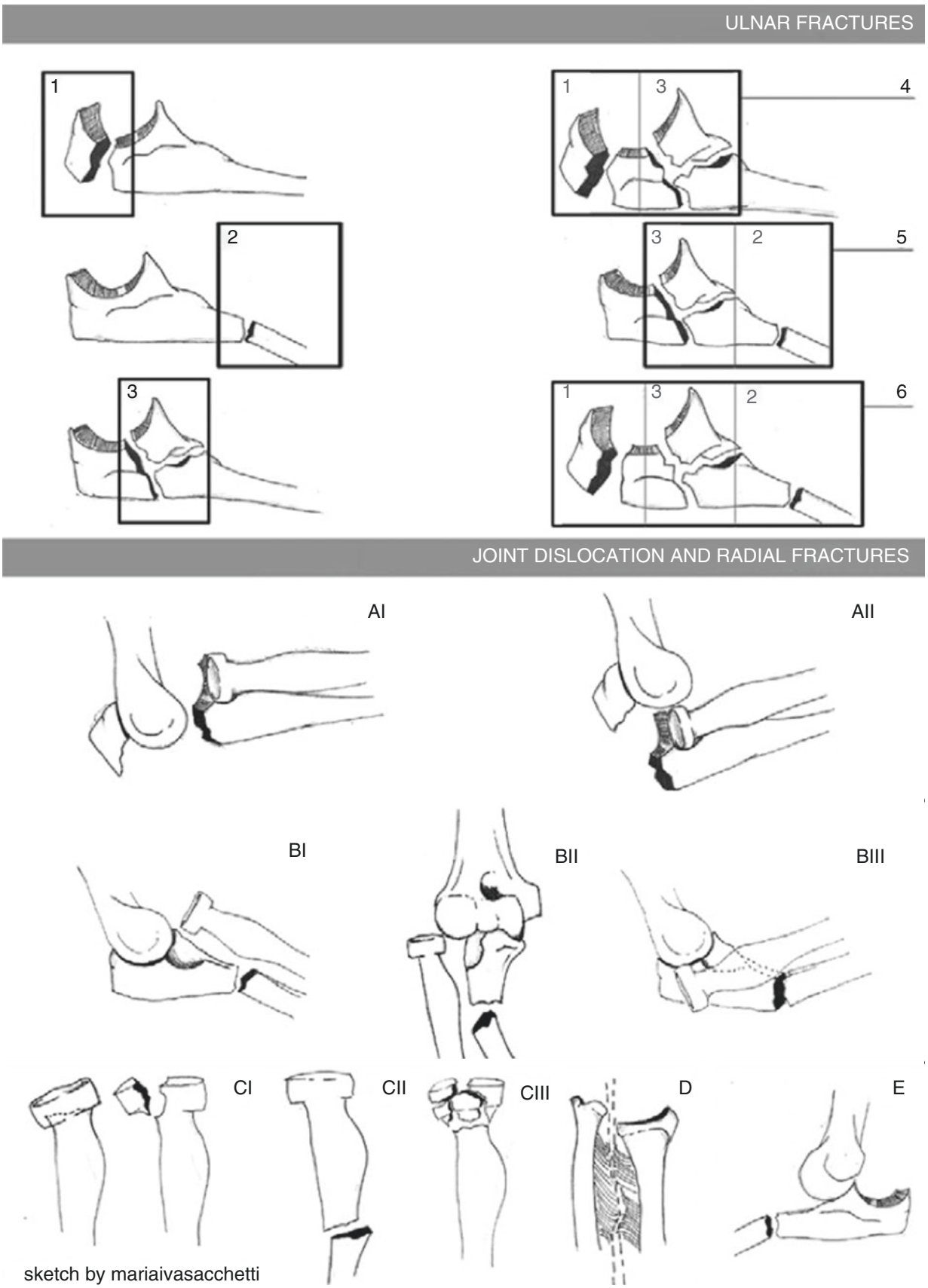


Fig. 12.9 Classification of fracture-dislocations of the proximal ulna and radius (PURCCS) (From: Giannicola G, Greco A, Sacchetti FM et al. (2011) Complex fracture-dislocations of the proximal ulna and radius in adults: a comprehensive classification. J Shoulder Elbow Surg. 20(8):1289–99)

reconstruction, whereas the latter are frequently associated with persistent instability, even after ulnar osteosynthesis, because of the damage to the LCL complex. We believe that by increasing the accuracy when diagnosing a transolecranon fracture-dislocation (type A) or a Monteggia-like lesion (type B) is more likely to result in the most appropriate treatment for these injuries being selected.

Injury to the distal radio-ulnar joint (DRUJ) (type D) was included among the main lesions because it may be associated with FDUR and require additional treatments (Gul et al. 2007; Josten and Freitag 2009). As a further main lesion, we included the ulno-humeral joint dislocation (type E), which is typically associated with complex shaft ulnar fractures. This rare injury results from a high-energy trauma and is characterized by the association between complex soft tissue damage and an ulnar fracture, which is frequently comminuted; the prognosis in such cases tends to be poor (Karlstad et al. 2005; Mouhsine et al. 2007; Strauss et al. 2006). The presence of a radial fracture (type C) is an additional factor that plays an important role in the prognosis of elbow fracture-dislocations (Eathiraju et al. 2007; Givon et al. 1997; Jupiter et al. 1991; Llusa Perez et al. 2002; Penrose 1951). We described three types of radial fractures that require specific treatment, in keeping with the Hotchkiss classification (Hotchkiss 1997).

This classification helps to identify the main lesions of each injury FDUR pattern, while the associated detailed therapeutic algorithm (Table 12.2) helps to select the correct surgical strategies. In particular, before surgery is planned, the following questions should be addressed: (1) To what extent has the ulna been injured (from type 1 to type 6)? (2) Is the radio-humeral joint alone involved (type A lesion) or is it associated with a proximal radio-ulnar joint dislocation (type B lesion)? (3) Is the radius fractured (type C), and if so, what type of fracture is it? (4) Are the elbow joints alone involved or are the interosseous membrane and the DRUJ (type D) also involved? (5) Lastly, is an ulno-humeral dislocation (type E) present? When answering these questions, the surgeon should bear in mind all the possible main lesions that need to be treated to achieve good results. In a case series of 39 FDUR cases classified and treated according to the PURCCS, we achieved satisfactory clinical results in the majority of patients, with few major complications or re-interventions (Giannicola et al. 2013b) (Fig. 12.10). The MEPS, Dash score and m-ASES score in this series were, respectively, 91.2, 14.9 and 83.9.

Table 12.2 Therapeutic algorithm of the classification of fracture-dislocations of the proximal ulna and radius (PURCCS)

Fracture type	Aim of treatment (*type of injury*)	Type of surgery
Type 1	Trochlear notch reconstruction (*bone and cartilaginous damage*)	Osteosynthesis with precontoured plate or tension band wiring. Bone graft if necessary
Type 2	Restoration of ulnar length, alignment and rotation (*bone damage*)	Osteosynthesis with precontoured plate Bone graft if necessary
Type 3	Articular reconstruction and restoration of elbow stability (*bone, cartilaginous and ligamentous damage*)	Coronoid osteosynthesis, precontoured plate for ulnar fractures, bone graft if necessary, ligament reconstruction +/− hinged elbow fixator
Type 4	Type 1 + type 3	Type 1 + type 3
Type 5	Type 3 + type 2	Type 3 + type 2
Type 6	Type 1 + type 2 + type 3	Type 1 + type 2 + type 3
AI–AII	Recovery of radio-humeral joint stability through trochlear notch reconstruction (*cartilaginous and bone damage, possible ligamentous damage*)	Osteosynthesis with plate or tension band wiring, bone graft if necessary. LCL repair if persistent joint instability (rare)
BI–BIII	Recovery of radio-humeral and proximal radio-ulnar joint stability (*ligamentous damage*)	LCL and annular ligament reconstruction
CI	Radial head reconstruction (*bone and cartilaginous damage*)	Osteosynthesis with pins, headless screws or plate
CII	Restoration of radial length, alignment and rotation (*bone damage*)	Osteosynthesis with plate Bone graft if necessary
CIII	Replacement of radial head (*bone and cartilaginous damage*)	Radial head prosthesis
D	Restoration of forearm longitudinal stability (*ligamentous and IOM damage*)	DRUJ stabilization with pinning +/− reconstruction of TFCC. Radial head osteosynthesis or replacement
E	Restoration of elbow stability (*ligamentous damage*)	LCL repair, +/− LCM repair and/or hinged external fixator

From: Giannicola G, Greco A, Sacchetti FM et al. (2011) Complex fracture-dislocations of the proximal ulna and radius in adults: a comprehensive classification. J Shoulder Elbow Surg. 20(8): 1289–99

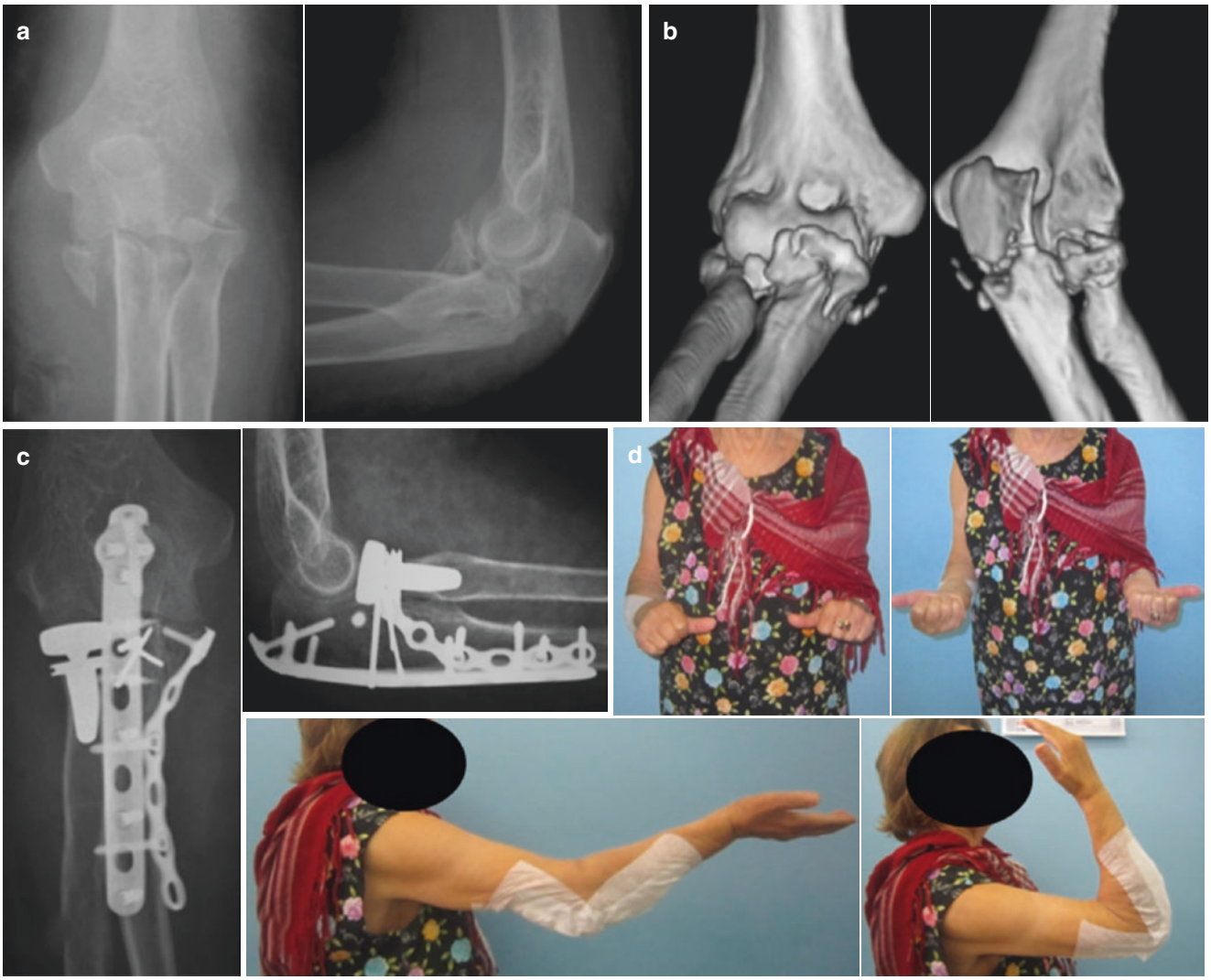


Fig. 12.10 Type 3 BIII CIII lesion according to the PURCCS: Preoperative standard X-rays (**a**) and 3D computed tomography reconstruction (**b**). Postoperative radiographs (**c**) and clinical result (**d**) at 14 days after surgery

12.2.5 Humeral Shear Fractures Associated with Lateral and Medial Collateral Ligament Lesions

Humeral shear fractures are a rare injury involving the capitellum and trochlea that account for 1% of all elbow fractures and 6% of distal humeral fractures; the incidence of such fractures is higher among women than in men because the former suffer from osteoporosis more than the latter (Yari et al. 2015). The mechanism of injury usually involves a fall on an outstretched arm, which causes direct axial and valgus compression transmitted to the capitellum by the radial head (McKee et al. 1996). Several classifications have been proposed for this kind of fracture, the most commonly used being the one by Bryan-Morrey. In 2006, Dubberley et al. (Dubberley et al. 2006) classified humeral shear fractures according to three types: type 1, involving the capitellum with or without the lateral trochlear ridge; type 2, a fracture of the capitellum and trochlea as a single piece; and type 3, fractures of both the capitellum and the trochlea as separate fragments. These fractures were further divided depending on the absence (A) or presence (B) of posterior condylar comminution because osteosynthesis may be more challenging in the latter.

Coronal shear fractures often occur in isolation with a stable elbow, but may sometimes be involved in a more complex elbow injury with other osseous and soft tissue constraint

lesions. In particular, an associated radial head fracture has been observed in up to 30% of cases (Ashwood et al. 2010; Dubberley et al. 2006; Lee and Lawton 2012; Mighell et al. 2010; Yari et al. 2015), while an association with an olecranon or coronoid fracture is rarer (Goodman and Choueka 2005; Ruchelsman et al. 2008; Watts et al. 2007). Ruchelsmann observed that four out of five associated radial head fractures in his series occurred in type 4 fractures, assessed according to the Bryan-Morrey classification (Sabo et al. 2010). Some studies have reported LCL lesions in up to 40% of cases (Ashwood et al. 2010; Dubberley et al. 2006; Lee and Lawton 2012; Mighell et al. 2010). In a series of 18 patients, Mighel et al. (Mighell et al. 2010) found that a LCL injury was more often associated with injuries involving the capitellum and trochlea as one piece than with isolated capitellum fractures. Giannicola et al. (Giannicola et al. 2010b) described a case series of 15 patients affected by humeral shear fractures treated with ORIF and hinged external fixation. Four of these 15 cases had an elbow dislocation associated with both collateral ligament disruption, while another 4 patients had a MCL tear.

These recent observations suggest that shear fractures associated with elbow dislocation or lateral and medial collateral ligament tears may represent a pattern of CEI in which bone failure occurred on the humeral side rather than on the ulnar and radial side (Fig. 12.11). It is for this reason that we decided to include this type of lesion in this chapter even if there is as yet no consensus on this topic. It is important to stress that this type of injury should be differentiated from monocondylar fractures of the distal humerus, which are unstable as a consequence of the fragment displacement that includes the collateral ligament. In the latter case, the condylar ORIF directly restores elbow stability, while ligament reconstruction is required after ORIF in case of shear fractures associated with ligament lesions; in such cases, the pathoanatomical finding of soft tissue constraint lesion is, in our experience, analogous to that observed in other CEI patterns (Giannicola et al. 2010b).

On the basis of these considerations, the same therapeutic algorithm of CEI should be applied to this type of injury. Briefly, correct surgical treatment includes stable osteosynthesis with headless screws and ligament repair, as also advocated by other authors (Singh et al. 2010). There is currently no consensus on the optimal method of fixation for these fractures. Headless compression screws are widely adopted. A biomechanical study has shown that placing headless compression screws in an anteroposterior fashion is superior to placing cancellous screws in a posterior-to-anterior fashion (Elkowitz et al. 2002). Furthermore, placing screws in an anterior-to-posterior fashion prevents disruption of the posterior soft tissues, thereby preserving the distal humeral blood supply more effectively.

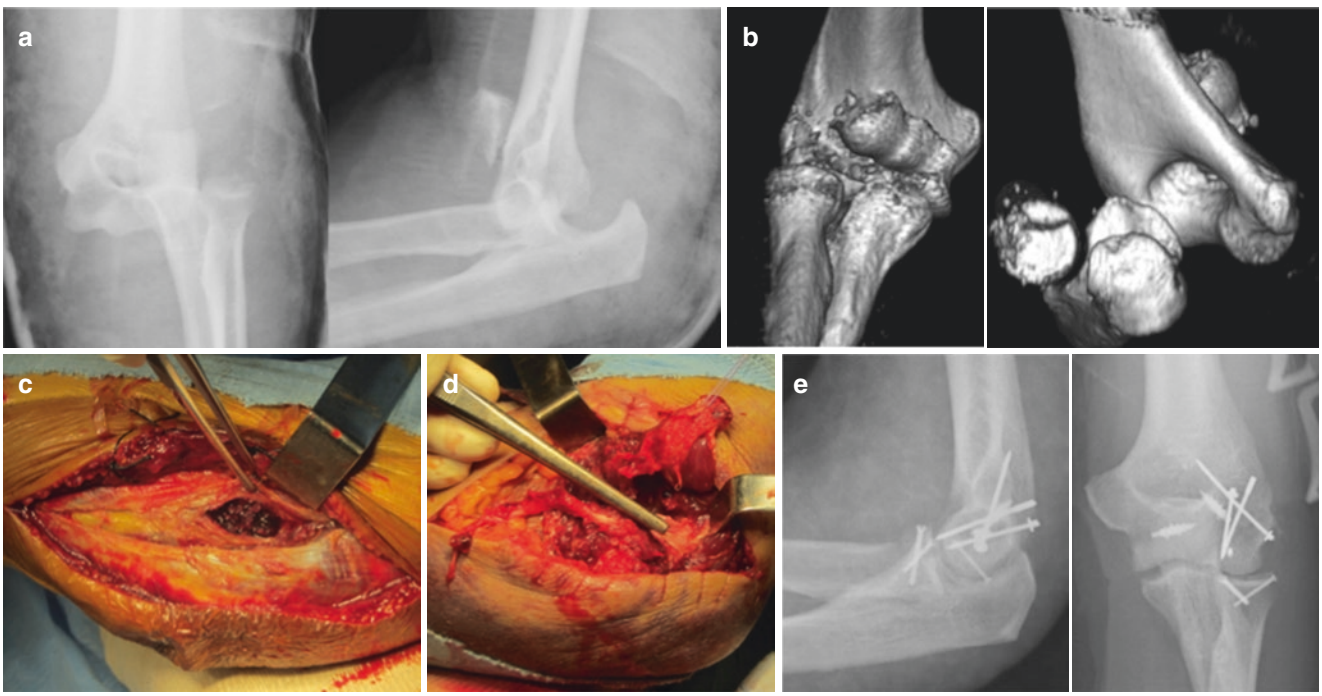


Fig. 12.11 Shear fracture of the capitulum humeri and trochlea associated with posterior dislocation, radial head Mason type 2 fracture and anteromedial side skin wound: Preoperative standard X-rays (**a**) and 3D computed tomography reconstruction (**b**). Intraoperative photograph showing a lateral (**c**) and medial (**d**) soft tissue constraint injury. Postoperative X-rays at 5 days after surgery (**e**)

When posterior comminution is present, supplemental fixation with a plate and bone graft might be necessary. After ORIF, the LCL needs to be repaired in all cases and the stability checked. The remaining surgical steps are the same as those described for the other CEI patterns. Capitellar excision is another option, though it may lead to complications, such as elbow instability, and should thus be reserved for small, unfixable fractures, whereas ORIF should be performed whenever possible. Indeed, a recent biomechanical study showed that even small impaction fractures of the posterior part of the capitellum contribute to a loss of radiocapitellar stability, particularly in elbow fracture-dislocation (Shukla et al. 2015). Capitellar prosthesis, humeral hemiarthroplasty or total elbow arthroplasty should therefore be considered in patients with non-repairable fractures.

12.3 Postoperative Treatment

When surgery ends, two drainages are applied (one endoarticular, the other subcutaneous), and the elbow is immobilized in a plaster splint for the first 48 h. The position of the elbow is usually chosen at the end of the surgical procedure after joint stability has been assessed by means of fluoroscopy; the elbow should be positioned in maximum extension to avoid both anterior bleeding and flexion contracture. The upper limb is placed in the elevated position, and cryotherapy and analgesic therapy are administered. Pharmacological prophylaxis for heterotopic ossifications with indomethacin (100 mg daily) is usually administered in all patients after the second postoperative day for 5 weeks. Once the drainages have been removed (after 48 h), a hinged elbow brace is applied for 45 days to protect joint reconstruction in the early phases of rehabilitation. In addition, the use of a compression arm sleeve for 3–4 weeks after surgery might help to minimize swelling and improve blood circulation.

When a hinged external fixator is implanted during surgery, it is kept locked in extension for 48 h and unlocked thereafter. The device is usually removed between 6–7 weeks after surgery to allow soft tissue lesion/reconstruction to heal properly.

12.4 Rehabilitation

When stable osteosynthesis of all osseous lesions and a valid reconstruction of soft tissues are achieved during surgery, early mobilization should be performed. In such cases, the elbow rehabilitation programme may begin within 2 days of surgery.

The rehabilitation programme is divided in three phases: (1) the ‘acute phase’, defined as a stage of bone non-union, which usually lasts between 0 and 6 weeks post-injury, or until union occurs; (2) the ‘subacute phase’, defined as the next stage after bone healing, which occurs between 6 and 12 weeks post-injury; and (3) the ‘functional phase’, which starts after 3 months (Giannicola et al. 2014).

In the acute stage, patients are instructed on rest, limb elevation, precautions, activity modification and pain management. In the first 7 postoperative days, passive range of motion (PROM) exercises are started, whereas active assistive range of motion (AAROM) and active range of motion (AROM) are allowed after the first and the second postoperative weeks, respectively, under the supervision of the personal therapist. In the first 3–4 weeks, early protected ROM exercises should be performed in a supine overhead position with the shoulder flexed to 90° to reduce the effects of gravity by minimizing posterior vector forces at the elbow. Moreover, in this position, the triceps can be used as an elbow stabilizer (Alolabi et al. 2012). It is very important that the patient be adequately instructed on how to perform the gravity-assisted exercise correctly, since internal rotation and abduction of the shoulder place varus stress on the repaired or injured lateral ligament and coronoid AMF fractures, thereby increasing the risk of surgical failure (Wolff and Hotchkiss 2006).

In addition, the therapist should treat the wrist, hand and shoulder to avoid secondary stiffness. Our advice is to perform assisted physiotherapy five times a week for an hour each time. Moreover, patients should start an exercise programme at home, consisting of at least five 20-min sessions per day. A detailed exercise book is used in our institution as a valid support (Giannicola and Zangrando 2012).

Certain restrictions, which depend on the CEI patterns and type of surgery performed, are observed in the first 6 weeks after surgery. For example, elbow extension is limited to 30° for the first 25 days postoperatively during the extension-flexion exercises in patients with anterior coronoid fractures repaired with transosseous sutures. Moreover, in the first 4–6 weeks, during the extension-flexion exercises, the forearm is positioned in pronation in cases in which reconstruction of the lateral collateral ligament is weak or supination in cases in which MCL deficiency persists or the ligament could not be repaired; in cases in which both ligaments are repaired, the forearm is positioned in neutral rotation. Complete forearm rotation exercises are often allowed immediately at 90° of flexion.

The second (‘subacute’) and third (‘functional’) phases of the rehabilitation should be focused to a greater extent on the restoration of elbow function; the hinged elbow brace can be dismissed after the sixth week, and patients are allowed to continue AROM, AAROM and PROM exercises and to follow the home programme (from the sixth to twelfth weeks). Stretching, strengthening and functional exercises are also started after the 12th week and after bone healing. Usually, driving the car is allowed after the 8th-10th post-operative week, taking care not to elevate and intrarotate the shoulder of the affected arm. Sport activities and manual work can be resumed after 6 months.

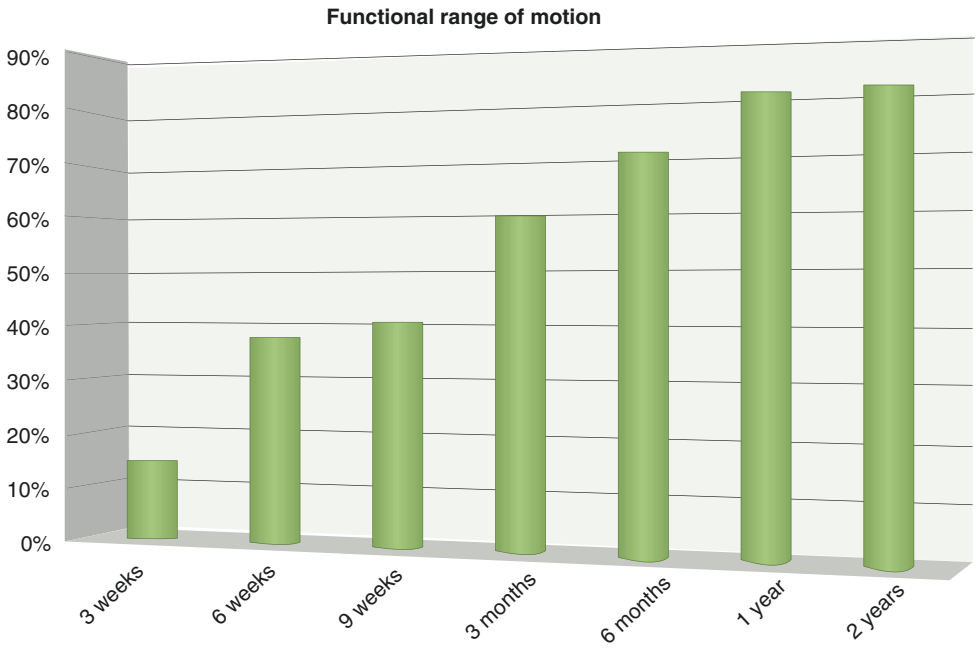


Fig. 12.12 Percentage of patients that recovered or exceeded a functional range of motion (extension-flexion 30°–130° and pronation-supination 50°–50°) during the follow-up

In a recent published study, we reported our experience with this rehabilitation protocol in a series of 76 patients affected by complex elbow instability. The study showed that 70% of the patients recovered functional ROM between the third and sixth months, though the recovery of flexion proved to be slower than that of the other elbow movements. This is likely due to the fact that in the first 6 weeks patients were protected by a hinged brace that prevented flexion beyond 120° and to even less than 120° in patients with a larger arm. Thereafter, improvement continued, though at a lower rate, until the end of the first year, when approximately 80% of the patients had recovered functional ROM (Fig. 12.12).

Following surgical treatment of CEI, a rehabilitation programme needs to be started promptly and continued for at least 6 months because the most significant improvement in ROM occurs in this period, which should be considered critical to obtain a functional elbow in a majority of patients. The surgeon's dilemma in the management of these complex elbow injuries is, however, that unless the elbow joint is carefully reconstructed and the patient is fully compliant, instability may recur during the first postoperative weeks; some surgeons thus prefer to immobilize the elbow for 3–4 weeks to avoid intrinsic stiffness due to secondary fracture displacement or ligament reconstruction failure. When this period of immobilization is adopted, a certain amount of extrinsic stiffness is to be expected, and the patient should be informed about this possible development (Harding et al. 2011; Issack and Egol 2006; Keschner 2007; Kodde et al. 2013; Morrey et al. 1981; Morrey 2005).

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Radial Head Fracture: Synthesis or Prosthetic Replacement

13

Andrea Celli and Susanna Stignani Kantar

13.1 Introduction

Radial head fracture is the most common elbow fracture in adults. Its incidence ranges from 1.7% to 5.4% of all adult fractures (Harrington and Tountas 1981; Mason 1954; Herbertsson et al. 2004a; Tejwani and Mehta 2007; Duckworth et al. 2012a; Kaas et al. 2010), and approximately 85% of these fractures occur in active individuals (from 20 to 60 years old).

The most common traumatic mechanism is a fall onto the outstretched hand with the elbow partially flexed and the forearm in pronation. This position results in axial force transmission from the hand, through the wrist and forearm, and it is related to an impaction of the radial head against the capitellum. It may also occur from direct or penetrating trauma or as consequences of a high-energy trauma.

The fracture pattern ranges from non-displaced to comminuted radial head fractures may be an isolated fracture, but more frequently it is a part of a complex injury (complex elbow dislocation) in association with other elbow fractures (the olecranon fracture with or without the coronoid fracture), ligament injuries (the lateral collateral ligament, the medial collateral ligament), or an elbow dislocation.

Many treatment options exist, including nonoperative management, internal fixation, arthroplasty, and resection.

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13.2 The Anatomy and Biomechanical Roles of the Radial Head

The radial head aspect is a disc-shaped structure approximately 3.5 mm thick. It is not round and shows significant difference between orthogonal diameters as ovoid rather than circular (2.5 cm longer in the anteroposterior plane and 2.2 cm in the coronal plane).

It has a shallow proximal depression covered by hyaline cartilage articulating with the capitellum as well as the 250 degrees arc of circumference that articulates with the lesser sigmoid notch; the remaining part of the circumference is not involved in the forearm rotation, and it is not entirely covered by the hyaline cartilage. This area is called "safe zone," and it is the place where the internal fixation devices are best applied (Smith and Hotchkiss 1996).

The lateral collateral complex and the annular ligament are important stabilizers of the proximal radius. In particular the annular ligament allows the rotation but prevents proximal migration of the radius contrasting the biceps forces that are present during the elbow flexion.

Biomechanical studies have reported as the radial head has an important role in the elbow and forearm stabilizer. Morrey et al. (1991) demonstrated that the radial head serves as a secondary constraint of the elbow to valgus stress, in association with the anterior bundle of the medial collateral ligament (Fig. 13.1).

Radio-capitellar joint congruency also helps to stabilize the joint; it resists external valgus forces and serves as a mechanical block to proximal migration of the radius (longitudinal stability of the forearm).

Load transmission from the wrist to the elbow occurs through the radius, the ulna, the interosseous membrane, and the triangular fibrocartilage complex (Morrey et al. 1988; Rabinowitz et al. 1994) (Fig. 13.2). The radius transfers more than 60% of the forearm loads (Morrey et al. 1988; Hotchkiss 1997; Rozental et al. 2003).The most force is transmitted to the radial head with the elbow extended and forearm pronated (Morrey et al. 1988).

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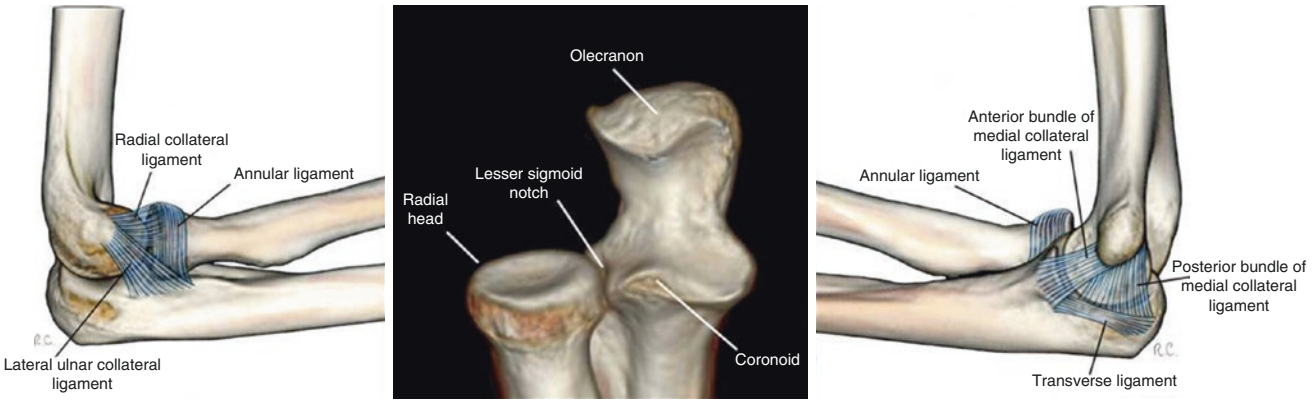


Fig. 13.1 The radial head aspect is a disc-shaped structure, and it articulates with the lesser sigmoid notch. The lateral and medial collateral ligaments and the annular ligament are important stabilizers of the elbow joint

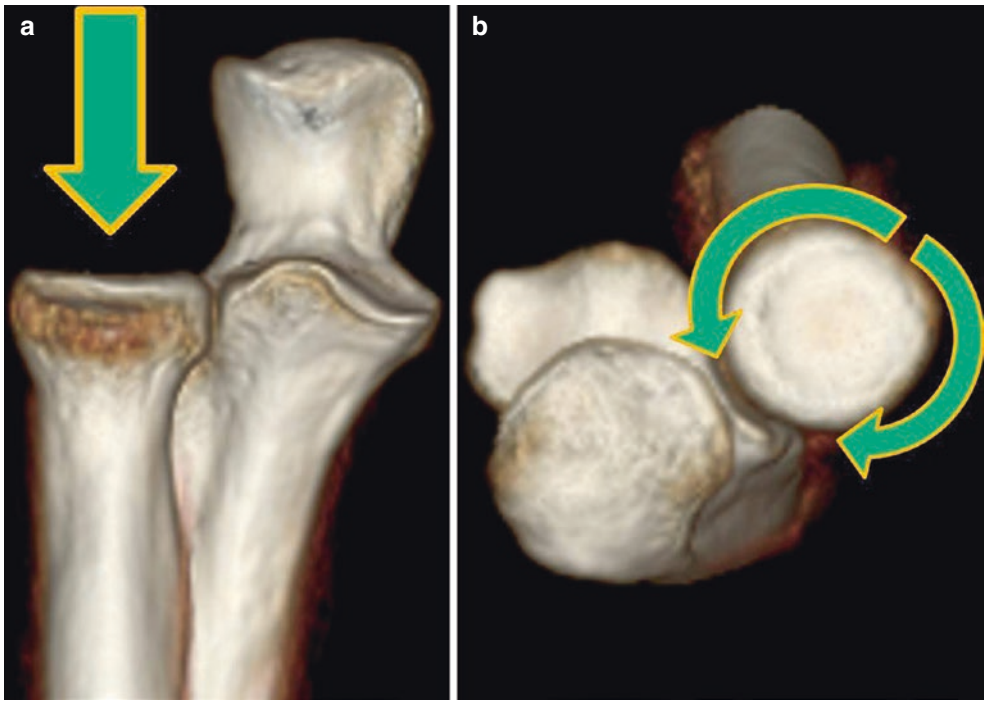


Fig. 13.2 (**a**, **b**) The radial head has an important role in the elbow and forearm stabilizer in the frontal, sagittal, and transverse planes, and it has to control the compression (**a**) and torsion (**b**) forces

If the interosseous membrane and the ligaments of the distal radioulnar joint are damaged from injury, the radius will migrate proximally, and the longitudinal and distal radioulnar dissociation occurs (Sowa et al. 1995; Hotchkiss 1994). Shepard et al. (2001) observed as for each millimeter of radial shortening, the distal ulnar load increases by approximately of the 10%.

In case of radial head excision, the transfer load changed, and the forces are transferred to the ulna from the distal radius through the interosseous membrane so the tension in the medial collateral ligament increases when a valgus stress is applied (Hotchkiss and Weiland 1987; O'Driscoll et al. 1991; Beingessner et al. 2004).

13.3 The Clinical Assessments

A spectrum of injury patterns often occurs in association with radial head fractures. A systematic clinical assessment is required to identify associated fractures and ligament injuries. Although tenderness over the radial head is ordinary, tenderness at other sites can be related to the presence of an associated injury.

Pain over the lateral epicondyle might indicate lateral collateral ligament injury, and over the sublime tubercle or the medial epicondyle might indicate a medial collateral ligament injury.

Pain and tenderness at the distal radioulnar joint or in the forearm should be related to an axial instability as in an Essex-Lopresti lesion (Essex-Lopresti 1951).

The range of motion in both planes will be reduced due to the presence of an intra-articular hematoma; limitation of forearm rotation can be due to a mechanical block from a displaced radial head fracture with the fragments that caused an impingement with lesser sigmoid notch or with the capitellum articular surfaces.

In acute lesions, the stability tests are often not possible without anesthesia.

13.4 The Imaging Assessments

The X-rays performed in the orthogonal planes with the addition of oblique views are important to define the radial head fracture and other bone injuries.

The X-rays have been used also to analyze the aspects of the capitellum, trochlea, and coronoid. Incongruence of the radio-capitellar or ulno-humeral joints suggests concomitant ligamentous injuries. In particular comminuted radial head fractures can be associated with coronoid fractures and ligamentous injuries as in the case of terrible triad lesion.

Computed tomography is particularly useful to better characterize fracture types. It is helpful to quantify the displacement, and it allows a better assessment of the reparability of the fracture fragments (Guitton et al. 2010) (Fig. 13.3).

Magnetic resonance imaging can provide more information regarding associated soft tissue injuries of the collateral ligaments and the interosseous membrane of the forearm. Other injuries that can be identified are the chondral lesions and loose bodies.

13.5 The Classifications

The most common classification for radial head fractures was described by Mason (1954) in 1954. Johnston (1962) modified this in 1962 to include a Mason–Johnston type IV lesion.

Mason's original classification (Mason 1954) was modified by Broberg and Morrey (1987) to quantify the extent of head involvement and to include radial neck fractures.

- Type I: fracture of the radial head or neck with 2 mm displacement
- Type II: fracture of the radial head or neck displaced 2 mm and involving 30% of the articular surface
- Type III: comminuted fracture of the radial head or neck
- Type IV: elbow dislocation with fracture of the radial head

Hotchkiss (1997) described a modified classification that aims to direct treatment.

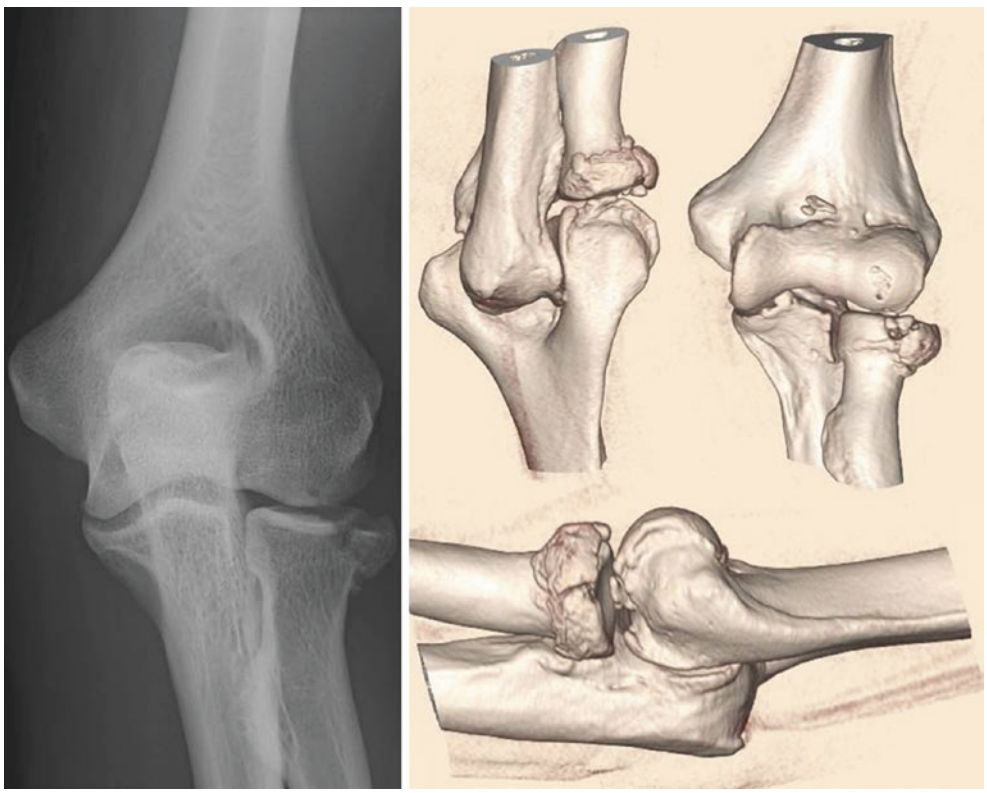


Fig. 13.3 Computed tomography is useful to better characterize fracture types and the entity of the displacement

- Type I: minimally displaced fracture with no mechanical block to motion and intra-articular displacement of 2 mm or a marginal lip fracture
- Type II: displaced 2 mm fracture of the head or neck without severe comminution and with or without a mechanical block to motion
- Type III: severely comminuted fracture of the radial head or neck with or without a mechanical block to motion

An important aspect in determining appropriate treatment includes recognizing associated injuries and considering their implications (Van Riet and Morrey 2008).

Ring (2008) summarized the most common injuries that occur in association with radial head fractures:

- Elbow dislocation and subluxation
- Medial collateral ligament rupture or capitellar fracture
- Terrible triad injuries (radial head fracture, coronoid fracture, and elbow dislocation)
- Posterior trans-olecranon fracture–dislocation (posterior Monteggia)
- Interosseous membrane rupture (Essex-Lopresti)

13.6 The Treatment Options

Many factors should be considered in the decision-making process to ensure optimal outcomes. The characteristics of the radial head fracture, including fragment number, displacement, articular surface involvement, and bone quality, all influence the treatment. It is also imperative to establish the presence of associated ligamentous injury or associated elbow fractures or dislocation.

A variety of treatment options are used, including early motion with nonsurgical treatment or with a surgery by the fragment excision, radial head excision, repair, and replacement. The principal goals of all the treatments are to restore the elbow motion, and in case of the surgical treatment, the primary aims are to restore the anatomy and the articular congruity.

Non-displaced or minimally displaced fractures are common and represent approximately 40–50% of all radial head fractures, and they are considered stable (Akesson et al. 2006; Herbertsson et al. 2004b).

Minimally displaced fractures with no mechanical block to motion without instability should be treated nonoperatively with an early mobilization.

After trauma, aspiration of the elbow joint decompresses the joint, and an intra-articular injection of local anesthetic can dramatically decrease the pain. This permits a better evaluation of the range of movements and of the stability. However, Holdsworth et al. (1987) neglected to find a significant improvement in outcome after this procedure.

Although early mobilization should be encouraged, a study by Radin and Riseborough (1966) advised to proceed cautiously with fractures involving more than one third of the articular surface, as further displacement can occur. Regular follow-ups with radiographs are essential to ensure that delayed displacements of the fracture are not missed (Weseley et al. 1983).

Different studies have reported 85%–95% good results when isolated displaced partial (two-part) radial head fractures are managed nonoperatively with early active motion (Akesson et al. 2006; Herbertsson et al. 2004b). After excluding a mechanical block, the primary concern in the management of these lesions is the prevention of the elbow stiffness.

The exact displacement of a radial head fracture that predicts good outcome with nonoperative treatment has not been established.

Fractures, involving less than one third of the articular surface with less than 2 mm of displacement or in low demand populations (elderly patients), are at low risk of further displacement (Beingessner et al. 2004; Radin and Riseborough 1966).

Following the risk of secondary displacement of the fragments in particular in young active patients, some authors advocate operative fixation of all partial displaced articular fractures (Johnston 1962; Miller et al. 1981; King et al. 1991; Ikeda et al. 2003; Esser et al. 1995).

13.7 Surgical Treatments

Excision of radial head fragments involving more than 25% of the surface area of the radial head should be avoided (Beingessner et al. 2004). Capitellar fragments usually arise from the posterior aspect as a consequence of a posterolateral rotatory subluxation of the elbow and can be excised if they are less than approximately one-quarter of the capitellar surface (Caputo et al. 2006).

Radial head fragments involving more than one third of the articular surface should be fixed or replaced (Caputo et al. 2006).

Radial head resection can be considered in cases of isolated, displaced, and comminuted radial head fractures without instability (Van Riet and Morrey 2008). Following radial head excision, intraoperative fluoroscopic assessments (varus and valgus and axial stress examinations) of the elbow should be performed to exclude the presence of joint instability.

Some controversy is around the radial head excision. Follow-up studies demonstrate a high prevalence of radiographic arthritis that is sometimes associated with symptoms. (Boulas and Morrey 1998; Goldberg et al. 1986; Ikeda and

Oka 2000; Janssen and Vegter 1998; Morrey et al. 1979). The modifications of the elbow joint biomechanics following radial head resection can lead to premature cartilage wear (Beingessner et al. 2004).

Biomechanical analysis of elbows following radial head resection has shown altered kinematics and stability (Jensen et al. 1999) of the elbow joint. In particular Jensen et al. (1999) have defined the key roles of the ligaments in the setting of radial head resection, and they advise intraoperative varus, valgus, and axial stressing of the elbow and wrist to exclude an elbow instability or an Essex-Lopresti lesion.

Long-term outcomes are conflicting (Herbertsson et al. 2004a; Goldberg et al. 1986; Ikeda and Oka 2000). Herbertsson et al. (2004a) reported fair to good results after excision for Mason types II and III, with no significant difference in outcome between primary and delayed resection. Ikeda and Oka (2000) reported disappointing results after early excision for Mason type II and III.

13.8 Reduction and Internal Fixations

13.8.1 Arthroscopic Technique

The arthroscopy of the elbow has become a standard treatment option for many indications. It gives an excellent intra-articular view with soft tissues and articulate bone damage visualizations.

It was originally considered to be an unsafe procedure because of the small size of the elbow joint capsule and its close proximity to several neurovascular structures. Over the past decade, however, this procedure has become safer and more effective. These improvements can be attributed to a better understanding of elbow anatomy and of the pathologies.

The most common indications for elbow therapeutic arthroscopy procedures include removal of loose bodies, synovectomy, debridement, and excision of osteophytes and capsular release, but it can assist in effectively the diagnosis and management of acute intra-articular fractures.

It has been used in the treatment of minimally displaced radial head, coronoid and capitellum fractures in adults, and displaced radial neck and lateral humeral condyle fractures in children with good results (Van Tongel et al. 2012; Graveleau et al. 2006).

The arthroscope is also useful in the identification of varus, valgus, and posterolateral rotatory instability, particularly when these instabilities are not clear as to the acute clinical examination or if they are associated to radial head and coronoid fractures (Holt et al. 2004).

Most of the complications associated with elbow arthroscopy can be avoided by the proper surgical technique. Successful elbow arthroscopy requires a thorough understanding of the arthroscopic anatomy. The joint should be kept distended during the setup of the portals to move the neurovascular structures away from the arthroscopic devices.

The patient is placed in lateral or prone positions. Most of the procedures can be accomplished with the 4.0 mm 30° scope; 70° scope provides a better visualization of the radial head and capitellum.

In case of radial head fracture, the joint visualization is performed through the medial (proximal anteromedial and anteromedial) and lateral (proximal anterolateral and anterolateral) portals. The soft spot portal can be useful to reduce the fragment and to place the internal fixations.

A 3.5 mm shaver is useful for removing the hematoma and debris. Retractors can be used to pull out the annular ligament distally to allow direct access to the fracture fragments. Provisional reduction of the fragments can be obtained using "K-wires" in conjunction with probes and graspers (Baker and Brooks 1996). Definite fixation can be performed using absorbable pins or cannulated screws.

13.8.2 Open Technique

Articular displaced radial head fractures can be managed with open reduction and internal fixation, with good results (King et al. 1991; Ikeda et al. 2003). A block to rotation and the presence of associated fractures and ligament injuries can also influence the decision to proceed with an open reduction and internal fixation.

For radial head fracture fragments involving more than one third of the articular surface and causing a mechanical block, particularly in young and active patients, open reduction and stable internal fixation are recommended (Hotchkiss 1997; Beingessner et al. 2004).

13.9 Surgical Technique and Related Aspects

The patient is in supine position with the arm on the chest or on the arm holder.

Most commonly a lateral skin incision is used. The deep approach is typical through the Kocher approach (between the anconeus and the extensor carpi ulnaris muscles) or the Kaplan approach (extensor-splitting muscle approach). Both approaches offer adequate visualization and exposure for internal fixation of the radial head. When the medial and lateral sides of the elbow need to be addressed, the global approach using a posterior midline incision is preferred.

During the procedure, the interosseous nerve should be protected, i.e., with the forearm pronation that increases the distance between the radial head and the nerve.

A cadaver study on the radial head plating performed by Tornetta et al. (1997) reported that in only 1 (2%) of 50 arms. The posterior interosseous nerve lies directly on the radius, and the average distance from the radial head to the origin of the posterior interosseous nerve was at 1.2–1.9 mm, with average being proximal to the radial head in 31 cases. The muscular branch to the extensor carpi radialis longus was located from 7.1 to 1.8 mm from the radial head (Graveleau et al. 2006).

The radial head is exposed through the annular ligament and preserving the posterior bundle of the lateral collateral ligament. It is important to remain anterior to the equator of the radial head (anterior to the line drawn along the axis of the radius).

The debridement of the fracture is performed, and the reduction should be performed preserving as much as possible of the periosteum and the soft tissue around the radial head for keeping the integrity of the vascular supplies (Yamaguchi et al. 1997; Patel and Elliott 1999).

A fine "K-wire" can be used to manipulate fragments into position. If reducing the fragments results in a cancellous defect, bone graft can be harvested from the olecranon or the lateral epicondyle.

The concept of an anatomic "safe zone" must be reminded when a reduction and internal fixation is performed. Intraoperatively, the safe zone is defined by a 110° arc centered over the equator of the radial head with the forearm in neutral rotation (O'Driscoll et al. 2003): it is the portion of the radial head that is presented laterally under the wound with the forearm in neutral position (Smith and Hotchkiss 1996; Soyer et al. 1998) (Fig. 13.4).

Alternatively, the safe zone may be identified with the wrist in neutral; the zone lies between two longitudinal lines drawn from Lister's tubercle and the radial styloid proximally.

The cartilage of the safe zone is thinner and has a gray hue when compared to the remaining part of the radial head. Hardware may be placed into this zone without causing impingement with the lesser sigmoid notch.

A variety of devices can be used to achieve the goals of surgery, which consist of obtaining stable fixation, restoring the articular surface, and recovery the head-neck relationship.

Although current implants and techniques for internal fixation of small articular fractures have made it possible to repair most fractures of the radial head, data by Ring et al. (2008) suggest that open reduction and internal fixation are best reserved for minimally comminuted fractures with three or fewer articular fragments.

For fractures that do not involve the radial neck, the fixation is typically obtained by using small screws such as mini-fragment screws (sizes 2.0 or 2.7 mm). Screws should be countersunk beneath the articular surface, but not protrude through the opposite cortex. Fractures involving the radial neck are often impacted and require bone grafting to elevate the radial head. These fractures may be amenable to screw and plate fixations.

If plate is chosen for radial head and neck fixation, low-profile plates are indicated to reduce the impingement between the less sigmoid notch and the annular ligament.

In case of small fragments or in the presence of a piece of cartilage, the fibrin glue and bio-absorbable implants (K-wire and screw) can be used in particular if the fragment is not in the articular portion of the radial head (Givissis et al. 2008).

Early complications from internal fixation are usually a consequence of inadequate fixation, hardware malposition, or injury to the posterior interosseous nerve.

The most common late complications include hardware prominence (particularly in thinner individuals) and elbow stiffness with or without heterotopic ossification or the proximal radioulnar synostosis.

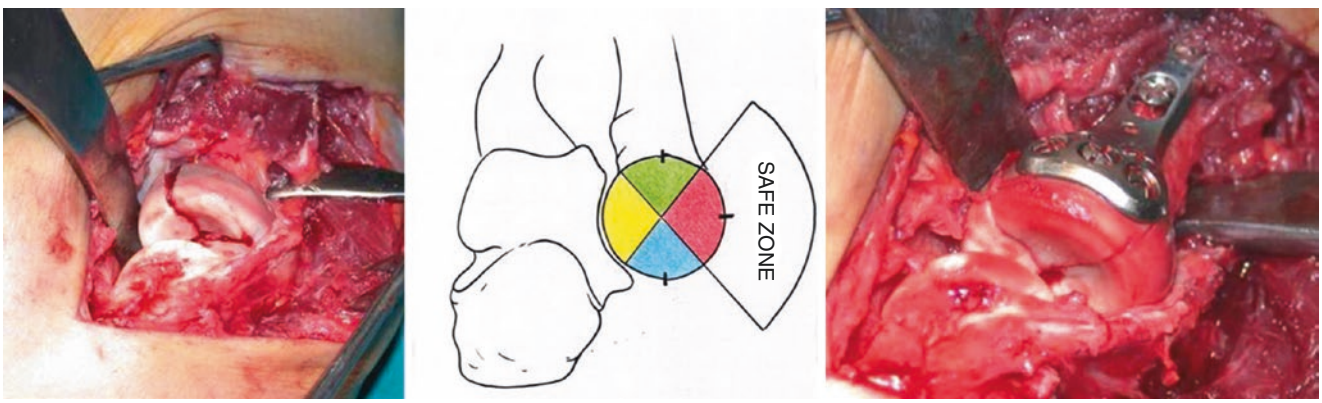


Fig. 13.4 The concept of an anatomic "safe zone" must be reminded when a reduction and internal fixation is performed, in particular when plate is chosen to reduce the risk of impingement with the less sigmoid notch

Regaining motion is an important goal after surgery that can be achieved with early active motion throughout the range of motion.

13.10 Outcomes and Related Considerations

Ring et al. (2002) presented a large series of patients (56 patients) with Mason types II and III fractures managed with internal fixation. The mean arc of motion after surgery ranges from 129° to 18° in flexion-extension, with a mean pronation of 67° and 59° in supination. Six patients had painful nonunion treated with radial head excision. They concluded that open reduction and internal fixation should be reserved for fractures with less than three articular fragments. All the patients with Mason type III fractures with more than three fragments had an unsatisfactory result, in contrast to all the patients with Mason type II fractures with satisfactory outcomes.

Ikeda et al. (2003) showed excellent results in ten patients, three of whom had a Mason type III fracture and seven with a type IV; all of them were treated with pre-contoured low-profile implants. The mean arc of motion in flexion-extension ranges from 135° to 7°, with a mean pronation of 76° and 85° in supination. However, 90% of the patients subsequently required hardware removal.

Esser et al. (1995) described nine Mason type III and six Mason type IV fractures treated with Herbert screws and AO mini-plates. In the first group, the mean arc of motion obtained ranged from 3° in extension to 138° in flexion, and the mean rotation was pronation at 86° and supination at 85°. In the second group, the arc of motion ranged from 13° in extension to 131° in flexion; the mean supination was 87° with 70° for pronation. No major complications were reported in both series.

Rolla et al. (2006) described an original technique for the arthroscopic diagnosis and treatment of the radial head fractures. This procedure was performed in six patients. Short-term preliminary results show a satisfactory functional outcome. The advantages of the technique are the minimal invasive approach and the direct visualization of the fracture.

Yeoh et al. (2012) reviewed the literature on the outcomes of elbow arthroscopy to obtain an evidence-based recommendation for this technique in the treatment of various conditions. They found some fair quality evidence for elbow arthroscopy in the treatment of rheumatoid arthritis and lateral epicondylitis. Poor quality evidence was also found for the arthroscopic treatment of radial head, capitellum, and coronoid fractures. They concluded that the available evidence supports the use of elbow arthroscopy in the management of these conditions, but the quality of the evidence is generally low.

13.11 Summary

- *X-rays and CT scan* are useful to define the preoperative plan and to assess the more adequate fixation.
- *Intraoperative fluoroscopy evaluation* is useful to assess the radial head reduction, the residual stability of the elbow and to check the impingement of the device with the lesser sigmoid notch and the capitellum during the motions.
- *Internal fixation* of the radial head is indicated in fractures with less than three fragments.
- *The common surgical approaches* are the Kocher and Kaplan exposures. The Kocher's approach allows the complete exposure of the lateral collateral ligament complex.
- *The lateral collateral ligament* should be preserved during the surgical exposure and in case of concomitant detachments from the bone insertions which have to be repaired.
- *The annular ligament* is incised to approach the radial head, and it should be repaired at the end of the procedure.
- *The posterior interosseous nerve* should be protected, keeping the forearm in pronation and avoiding compression forces using a Hohmann retractor or other devices around the radial head and neck soft tissues.
- *The hardware* should be placed in the non-articular safe zone to avoid any impingement with the lesser sigmoid notch. Check for any extraarticular placement of subchondral screws.
- *Ligament repairs* are an important step to be performed at the end of the procedure using heavy nonabsorbable sutures.
- *Postoperative motions* started as soon as possible also if the drainages are still in place. If there is a residual risk for a posterolateral instability or if the lateral ligament was repaired, the postoperative rehabilitation is performed with the forearm in pronation (the articular brace can be used to protect the motion).
- *Indomethacin therapy* can be used to reduce the risk of heterotopic ossification.

13.12 Radial Head Replacement

Radial head replacement is considered when the fracture is comminuted, and a stable internal fixation is not possible. It is also considered when the fracture involves more than one third of the radial head. It is particularly indicated for fractures with associated ligamentous injury and coronoid or olecranon fractures which are displaced or unstable.

For displaced radial head fractures with greater than three fracture fragments, open reduction and internal fixation has been reported to be less reliable, and radial head replacement may be the preferred technique. With these complex fracture patterns, it is difficult to maintain length and alignment during the fixation. Open reduction and internal fixation in the setting of comminuted fractures can result in nonunion, loss of fixation, and unpredictable forearm rotation (Ikeda et al. 2003; Ikeda et al. 2005; Bain et al. 2005).

In summary, the radial head replacement is indicated in the following acute situations:

- Acute comminuted fracture in which anatomic reduction and stable fixation cannot be obtained (Ring 2011)
- Complex elbow injuries that involve more than 30% of the articular rim of the radial head, which cannot be reconstructed
- Fractures with three or more fragments or significant comminution (Ikeda et al. 2003; Ring 2011)
- Intraoperative instability of the elbow after radial head resection (Hotchkiss 1997; Monica and Mudgal 2010)
- Essex-Lopresti lesion (Ring 2011)
- Associated terrible triad injuries (Smith and Hotchkiss 1996)
- Non-reconstructable radial head fractures with concomitant medial collateral ligament injury, interosseous membrane injury, or elbow dislocation (Monica and Mudgal 2010; Gao et al. 2013; Grewal et al. 2006; Pfaeffle et al. 2005).

Contraindications to radial head replacement in acute situations are:

- Active infection around the elbow joint
- Neurologic injuries (Ring 2011; Monica and Mudgal 2010; Gao et al. 2013; Grewal et al. 2006)

The modern radial head prosthesis is pyrocarbon or metallic implants. Silicone rubber prostheses are no longer used, as they are not rigid enough and are predisposed to the fragmentation (Vanderwilde et al. 1994).

The silicone flexibility limited its ability to transfer loads across the elbow (Carn et al. 1986). Another problem related to this device is the subsequent reactive synovitis and pain, as well as implant loosening (Gordon and Bullough 1982; Worsing et al. 1982; Morrey et al. 1981; Martinelli 2008).

The silicone implants are associated with bad clinical scores, increased elbow arthritis, and increased radial shortening.

Different implants are available for radial head replacement, and some of these try to replicate as much as possible the native radial head. Current prostheses are manufactured from cobalt–chrome alloys or titanium. Designs vary in respect to head shape and stem fixation techniques, including smooth, press fit, ingrowth, and cemented stems. Monoblock and modular prostheses are available, including bipolar

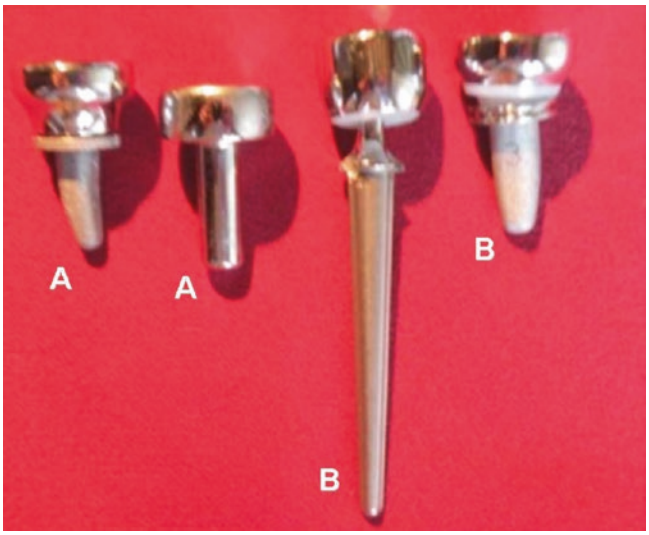


Fig. 13.5 Radial head prosthesis has different designs: unipolar (**a**) and bipolar (**b**), cup (head shape and sizing), material (metallic, pyrolitic carbon), *stem size* (short, long), stem fixation (cemented, press fit, loose fit, expansion screw)

implants. The recent radial head prosthesis can be classified according to the design concepts, such as bipolar versus monopolar, cemented versus uncemented, and anatomic versus an asymmetric head shape (Fig. 13.5).

Anthropometric studies of the proximal radius demonstrate that the head is elliptical in shape, it has a variable offset from the axis of the neck, and its diameter correlates poorly with the diameter of medullary canal of the neck (King et al. 2001). These findings may support that the use of modular implants allows improved sizing options that are more similar to the anatomy of the radial head and proximal radius.

13.13 Surgical Technique and Related Aspects

The radial head replacement as in case of the open reduction and internal fixation technique may be performed through a lateral or posterior approach. When concomitant fractures or complex injuries that involve the ligaments are present and require treatment, an extensile posterior approach is preferred. A skin incision is made between the lateral condylar ridge and the lateral aspect of the ulna through the mid-axial line of the radial neck.

The two cutaneous flaps are elevated and the subcutaneous sensitive nerves are protected. The dissection runs through:

1. The Kocher interval between the anconeus and extensor carpi ulnaris muscles
2. The Kaplan interval between the extensor carpi radialis longus and extensor digitorum communis muscles
3. The splitting of the extensor digitorum communis, as described by Hotchkiss (1997)

Using the Kocher approach, the lateral collateral ligament complex (LCLC) is exposed, and the annular ligament is prepared.

The lateral collateral ligament (LCL) is incised anterior to a line bisecting the articular surface of the capitellum from a lateral side (Hotchkiss 1997).

Inspection of the LCL complex should be performed. The elbow capsule and annular ligament should be incised in line with the posterior margin of the extensor carpi ulnaris. The capsule can also be incised in a ligamentous-sparing Z capsulotomy, as described by Bain et al. (2005). The capsule is elevated from the anterior distal humerus, and more of the radio-capitellar joint may be exposed by elevating the origin of the brachioradialis muscle.

The posterior interosseous nerve has to be protected avoiding traction and compression of the soft tissues around the radial head (Morrey 2009).

The pronation of the forearm without traction on the anterior soft tissues is useful to reduce the possibility of iatrogenic injury to the posterior interosseous nerve. Exposure provided by retractors, such as the Hohmann retractor placed anteriorly around the radial head or neck, is excellent; however, it is recommended to prevent any strong traction on the anterior soft tissue. If a wide exposure of the radius is necessary, we advise to release the supinator muscle from the ulna and to reflect medially both the heads of the muscle. In this way the radial neck and the proximal radial bone can be safely exposed by protecting the nerve. If the radial head needs to be moved out of the wound for better exposure, placing a small Hohmann retractor gently on the dorsal surface of the head will be helpful to elevate it out of wound preserving the posterior bundle of the LCL (Hotchkiss 1997).

Once the radial head is exposed, the degree of comminution and displacement is assessed.

The native head should be resected at the metaphyseal level proximally to the bicipital tuberosity, preserving the annular ligament and as much as possible of the radial neck. Once resected, it can be used to decide the adequate sizes of the cup of the implant (Ring 2004; Van Glabbeek et al. 2005; Van Glabbeek et al. 2004).

The aim of replacement is to replicate the native radial head anatomy as closely as possible paying special attention to the radial head size and height (King 2004). Different biomechanical studies have demonstrated the importance of accurate radial head sizing (Pomianowski et al. 2001; Van Riet et al. 2007).

The fractured head should be reassembled as closely as possible to the native one, and an appropriate head size is selected. Care should be taken to avoid overstuffing in the radio-capitellar joint because it has been associated with radio-capitellar wear and erosion (King 2004; Pomianowski et al. 2001; Van Riet et al. 2007).

It is important to check the radial neck for un-displaced fractures prior to insertion of the implant. Any un-displaced fractures should be prophylactically wired before prosthesis insertion because displacement or collapse may occur when the prosthesis is inserted.

An important mark is the proximal margin of the articular surface of the lesser sigmoid notch; in particular Doornberg et al. (2006) demonstrated using CT scans of 17 elbows that the native radial head lies an average of 0.9 mm distal to the proximal margin of the sigmoid notch, and this observation can be used during the radial head replacement to replicate the anatomical relationship (Fig. 13.6).

Van Riet et al. (2007) have shown that with the forearm in neutral rotation, the proximal edge of the lesser sigmoid notch can be used as a marker for the proximal end of the radial head. They showed that radial neck lengthening around

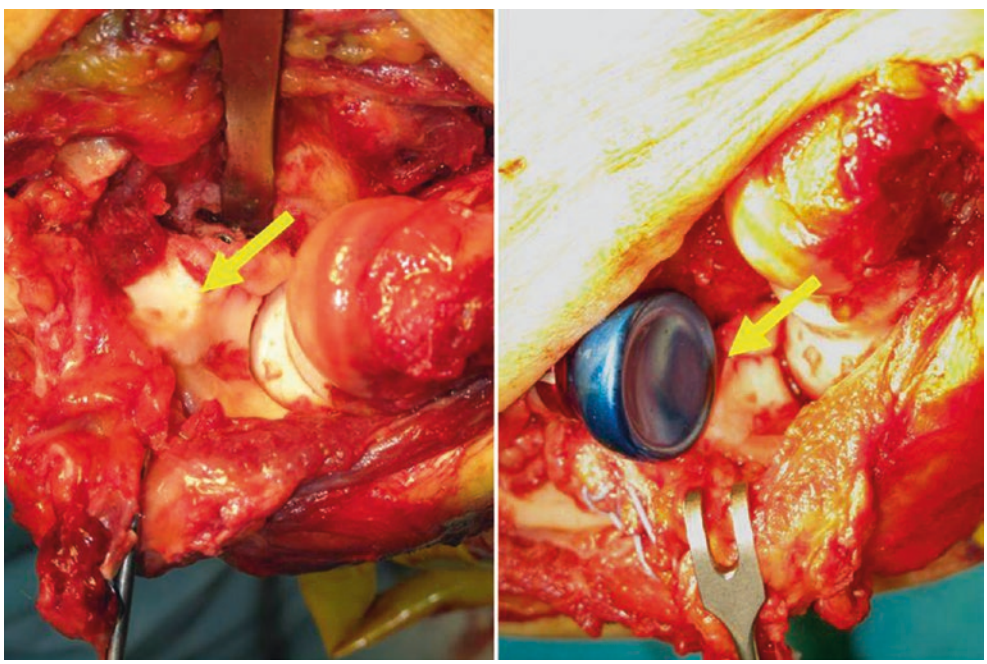


Fig. 13.6 The proximal margin of the sigmoid notch (*yellow arrow*) can be used during the radial head replacement to replicate the anatomical relationship

2.5 mm altered the radio-capitellar biomechanics, with a significant decrease in varus-valgus laxity and created an ulna mal-tracking. Radial neck shortening had the opposite effect (Fig. 13.7). Different authors recommended a smaller size implant than the native head, both with regards to diameter and thickness (King 2004; Pomianowski et al. 2001; Van Riet et al. 2007; Doornberg et al. 2006).

In general, it is preferable to be slightly undersized regarding the diameter and the thickness of the prosthesis (Ring and King 2008). A prosthesis, with a diameter that is too large, gives a load on the margins of the sigmoid notch, whereas a prosthesis that is too small gives a load on the sigmoid notch (King et al. 1999). A radial head with an incorrect diameter also has a cam effect, which produces abnormal loading on the capitellum. Insertion of a radial head that is too short contributes to radio-capitellar instability (King et al. 1999).

The medullary canal of the proximal radius is then prepared with serial-sized broaches until an adequate fit is obtained in the canal at the appropriate depth. The appropriate-sized trial stem is inserted ensuring that the collar of the prosthesis is flush with the resected neck. In modular designs, the trial head is secured to the trial stem, and the elbow and forearm are placed through a full arc of motion. Tracking as well as the relationship between the prosthesis and the capitellum is carefully assessed. Once acceptable alignment and tracking are determined, the trial components are removed, and the final prosthesis is inserted. The stem may be press fit or cemented in place depending on the design and stability of the stem in the medullary canal.

Inserting the stem may be difficult if the LCL is intact. An effective way to facilitate prosthesis insertion is to place a retractor under the radial neck and lever the proximal part of the radius anteriorly and laterally away from the capitellum (Ring and King 2008).

After the implant has been inserted, the elbow should be moved through a wide range of motion while the surgeon observes the radio-capitellar contact for congruency and tracking with the height and diameter of the implant. Elbow alignment and implant sizing can also be assessed by examining the parallelism of the medial ulno-trochlear joint space with fluoroscopy. The implant should articulate with the lateral trochlea at the level of the proximal radioulnar joint, approximately 2 mm distal to the tip of the coronoid (Van Riet et al. 2007; Doornberg et al. 2006). Distal radioulnar alignment and ulnar variance should also be examined. It is important to check for an over lengthening of the radius also using a fluoroscopy evaluation (van Riet et al. 2004).

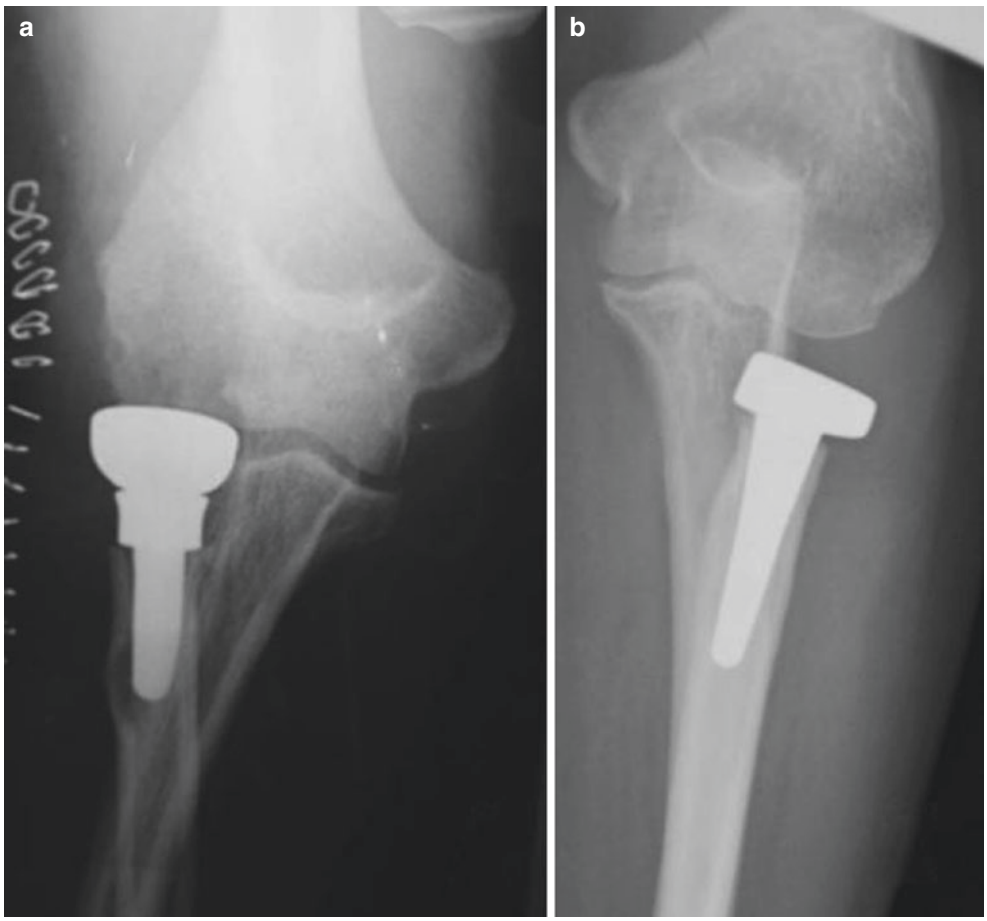


Fig. 13.7 (**a**, **b**) The radial neck lengthening (**a**) altered the radio-capitellar biomechanics, with a significant decrease in varus-valgus laxity and created an ulna mal-tracking. Radial neck shortening (**b**) had the opposite effect

The lateral collateral ligament complex is repaired to the lateral epicondyle with heavy nonabsorbable sutures using transosseous tunnels or suture anchors. The medial collateral ligament repair is not usually necessary, but if the elbow remains unstable after the radial head replacement and lateral ligament repair, it will be necessary.

Formal assessment of elbow stability as described by Bain et al. (2005) includes stress testing with the elbow in 30° flexion, and the forearm pronated is important. In this position, narrowing of the radio-capitellar joint by 2 mm with valgus stress testing is indicative of integrity loss of the anterior band of the ulnar collateral ligament. Transosseous sutures should be used for stabilization of the lateral collateral ligament with the elbow in 30° flexion and the forearm in full pronation (King et al. 1999).

Beingessner et al. (2004) reported in a biomechanical study that varus-valgus laxity was controlled after radial head replacement and lateral collateral ligament repair but not after the only radial head replacement without ligament repair. They noted only a small amount of valgus instability in elbows with disrupted medial collateral ligaments after radial head replacement.

13.14 Outcomes and Related Considerations

Good clinical results have been reported for metallic radial head implants for comminuted radial head fractures in a number of recent reports (Moro et al. 2001; Popovic et al. 2000; Smets et al. 2000; Zwingmann et al. 2013). However, the long-term effect on the capitellar articular cartilage and problems such as implant loosening and failure have been described.

Authors (Moro et al. 2001; Popovic et al. 2000; Smets et al. 2000; Zwingmann et al. 2013) observed as the correct diameter and height of the prosthesis is the key for a successful outcome. Using a larger diameter head will result in loading on the margins of the sigmoid notch, while an excessively small prosthesis will result in point loading. An incorrect head diameter can produce a cam effect, inducing abnormal load on the capitellum. The correct diameter of the radial head can be selected by comparing the excised and reassembled radial head fragments with the range of trial prostheses. The prosthesis should be congruent and have a smooth motion with the capitellum throughout the full range of motion (Bain et al. 2005; Pomianowski et al. 2001). The prosthesis should be seated on a stable rim of radial neck. Increasing the height results in overstuffing the joint, which may result in stiffness and lateral elbow pain, which has become a relatively commonly reported problem. A prosthesis that is inserted too short will result in instability (Markolf et al. 2004). To ensure a normal articulation with the proximal radioulnar joint, the height of the prosthesis must be the same as that of the trochlear notch.

Harrington and Tountas (1981) published one of the first series using titanium radial head prosthesis in 1981. The investigators reported good or excellent results in 14 (93%) of 15 patients at average follow-up of 6.9 years.

Bain et al. (2005) reported on 16 patients with Mason type III fractures treated with titanium prosthesis and found good to excellent results in 80% of them at 2.8-year follow-up.

Grewal et al. (2006) reported their experience using a metal modal implant on 24 patients with Mason type III fractures at an average of 25 months; they observed 12 excellent, 4 good, 6 fair, and 2 poor results.

Harrington et al. (2001) reported they experience using a metallic implant. The series included in 14 Mason type IV (comminuted fracture dislocations), 3 Monteggia fracture dislocations, 2 medial ligament tears associated with radial head fractures, and 1 Mason type II radial neck and coronoid. Sixteen patients out of 20 patients (80%) obtained a good or excellent outcome, based on the Mayo Elbow scores, at mean follow-up of 12.1 years (range 6–29 years). Only 6 (30%) of 20 were completely pain-free at final follow-up, but an additional ten had pain only with continuous activity. The investigators note degenerative changes of the capitellum in nine patients (45%).

Doornberg et al. (2007) reported as the majority of patients with loose fitting stems have radiographic lucency around the stem at follow-up. They followed up 27 patients (11 with Mason type II and 16 with Mason type III fractures) for an average of 40 months and reported average range of motion of 20° of extension, 131° of flexion, 73° of pronation, and 57° of supination. Twenty of 27 patients had excellent results on Mayo Elbow Performance score.

Knight et al. (1993) reported a reliable restoration of stability and prevention of proximal radial head migration after metal prosthesis in 31 patients at an average of 4.5 years' follow-up; 68% of the radial head fractures were associated with elbow dislocations. They noted a low complication rate and only two implants were removed for aseptic loosening.

Shore et al. (2008) studied 32 patients, with mean follow-up of 8 years (range 2–14 years), treated with delayed radial head replacement at an average of 2.4 years after the injury. The radial head fractures were associated with an elbow dislocation in 17 patients and terrible triad in 7 patients. The average Mayo Elbow Performance score was 83, with 21 (66%) obtaining good or excellent results. Post-traumatic arthritis was observed in 74%; they did not remove any implants.

Moro et al. (2001) retrospectively reviewed 25 patients with 10 Mason III and 15 Mason IV radial head fractures, treated with acute radial head replacement using a noncemented titanium prosthesis. At mean follow-up of 39 months (range 26–58 months), the investigators noted 16 (64%) good

or excellent results with 5 (20%) patients demonstrating radiographic evidence of posttraumatic arthritis. Heterotopic ossification was found in 8 (32%) patients.

Ashwood et al. (2004) studied outcomes in 16 patients treated with a titanium radial head prosthesis. The average Mayo Elbow Performance score at final follow-up (average 2.8 years) was 87 (range 65–100) with 13 (81%) obtaining good or excellent results, and 7 of 9 employed patients were able to return to work.

Rotini et al. (2012) described 31 radial head prostheses used in 30 patients. In ten patients, the mean time from trauma to surgical treatment was 2.4 days, while the remaining 20 patients were treated after an average of 19 days from trauma. The implant design was monopolar in 12 cases and bipolar in 19. At a mean follow-up of 2 years (range 13–36 months), the mean Mayo Elbow Performance score was 90 points. Heterotopic ossifications were found in 14 cases. Bone reabsorption was observed in nine cases; in their experience they found no significance evidence of a superiority of bipolar or monopolar designs.

Judet et al. (1996) reported their preliminary experience using the bipolar prosthesis on five patients with an average follow-up of 43 months, evaluated using the Broberg and Morrey score obtaining two excellent results. Afterward Judet et al. (2001) reported the results of a larger series of 22 cases treated using the bipolar prosthesis and evaluated using the Broober-Morrey score at an average follow-up of 12 months. Twenty-one satisfactory results and one unsatisfactory result were obtained.

Popovic et al. (2000) reported the use of bipolar prostheses in acute pathology on 11 patients with Mason type III fractures of the radial head associated with elbow dislocation; the date was analyzed using Booberg-Morrey, obtaining satisfactory results in eight patients; the remaining three patients presented an unsatisfactory result due to the presence of a limited range of motion and pain during everyday activities.

Smets et al. (2000) reported their experience using the bipolar prosthesis on 13 cases with a follow-up of 25.2 months evaluated using the Mayo Elbow Performance score: 7 proved to be excellent, 2 good, 1 sufficient, and the remaining 2 unsatisfactory, and one wherein the prosthesis had to be removed. The cause of the unsatisfactory result in three cases was pain with a limited range of motion.

Holmenschlager et al. (2002) published their experience in acute cases using the bipolar prosthesis on 16 patients, evaluated at an average follow-up of 18 months using the Booberg-Morrey score; 14 patients obtained a satisfactory result and two unsatisfactory one; these were patients with associated radius or coronoid process fractures.

Frosch et al. (2003) reported their experience with the bipolar implant on 10 patients with 11 implants. At an average follow-up of 5 years, nine patients (ten implants as one died due to causes not connected to the elbow injury) were assessed using the Broberg–Morrey score. Satisfactory results were obtained in seven patients (eight implants), and the remaining two were unsatisfactory.

Celli et al. (2010) reported their experience with a bipolar Judet radial head prosthesis for the treatment of the acute radial head fractures. Sixteen patients were assessed following radial head replacement with a mean follow-up of 41.7 months; the outcome was satisfactory in 87.5% of cases. The mean postoperative ranges of motion were greater than the functional arcs both in flexion-extension and in pronation-supination, and the results did not appear to be influenced in a significant way by the type of original lesion. All elbows were stable. The main complication was the development of heterotopic ossifications. They concluded that the bipolar radial head design represents a suitable option for acute treatment of irreparable acute radial head fractures. Afterward, the authors (Celli and Celli 2012) reported a larger group of patients treated using the same bipolar design (95 implants), and 70 patients were assessed; 39 patients (39 implants) underwent a radial head replacement for acute fractures, at a mean follow-up of 39.1 months; according to the Mayo Elbow Performance score, 32 were excellent, 2 good, 1 fair, and 4 poor.

The complications related to the implant design in this group are the disassemblage of the cup, the capitellar erosion, the overstuffing, and the posterolateral subluxation of the cup, but the majority of the complications observed are related to the joint as joint stiffness and heterotopic ossifications.

Ricon et al. (Ricon et al. 2012) performed a retrospective analysis of 28 patients with Mason III radial head fractures treated with a pyrocarbon radial head prosthesis. The radial head fracture was associated with an elbow dislocation in 23 patients. At an average follow-up of 23 months, patients had an average Mayo Elbow Performance score of 92 (range 70–100). The mean flexion-extension arc was 105 (range 65–130). Although these outcomes are comparable to those achieved with cobalt–chromium and titanium prostheses, enthusiasm should be tempered until longer-term follow-up data are not available.

13.15 Summary

- *X-rays and CT scans* are useful to assess the preoperative plan and to define the concomitant fractures.
- *Intraoperative fluoroscopy evaluation* is useful to assess the correct position and size of the radial head implant and also to assess the ulno-humeral articular space.
- *Radial head replacement* is considered when the fracture is comminuted and stable internal fixation is not possible.
- *Current implants* are manufactured from cobalt–chrome alloys or titanium. They can be classified according to the

design concepts, such as bipolar versus monopolar, cemented versus uncemented, and anatomic versus asymmetric head shape.

- *Lateral or posterior approaches* can be used to perform the radial head replacement similar to the open reduction and internal fixation technique. The deep exposure runs through the Kocher or the Kaplan interval.
- *The lateral collateral ligament complex* is incised anteriorly to a line bisecting the articular surface of the capitellum from a lateral side preserving the posterior bundle. The annular ligaments are incised too.
- *The posterior interosseous nerve* has to be protected; avoid traction and compression of the soft tissues around the radial head and neck.
- *The resection of the native head* should be at the metaphyseal level proximal to the bicipital tuberosity.
- *The radial head replacement* has to replicate the native radial head anatomy as closely as possible (paying special attention to the radial head size and height). It is preferable for the diameter and the thickness of the prosthesis to be slightly undersized.
- *The proximal edge of the lesser sigmoid notch* can be used as a marker for the proximal end of the radial head to avoid an over-lengthening.
- *Un-displaced radial neck fractures* have to be checked prior the insertion of the implant.
- *After the implant has been inserted*, the elbow should be put through a range of motion checking for the radiocapitellar contact and tracking with the height and diameter of the implant.
- *The lateral collateral ligament complex is repaired* to the lateral epicondyle using heavy nonabsorbable sutures through the transosseous tunnels or suture anchors.
- *The medial collateral ligament* is typically not necessary to repaired, but if the elbow remains unstable after the radial head replacement and lateral ligament repair, it will be necessary.
- *Postoperative motions* start as soon as possible even if the drainages are still in place. If there is a residual risk for a posterolateral instability or if the lateral ligament was repaired, the postoperative rehabilitation is performed, avoiding the complete forearm supination (the articular brace can be used to protect the motion).
- *Indomethacin* can be used to reduce the risk of heterotopic ossification.

13.16 Rehabilitation Aspects

The rehabilitation program of radial head fractures depends primarily on the presence of associated osseous and ligamentous injuries (simple or complex fractures, respectively) and if the patient has undergone surgery or not. In case of simple fracture surgery, the strength and stability of the repaired structures have to be clearly communicated by the surgeon to the physiatrist and therapist.

Non-displaced or minimally displaced fractures (Mason type II or II without mechanical block) are actually treated in a nonoperative way, and usually the extent of the trauma is not so heavy to create associated lesions. So the elbow rests in a collar and cuff sling flexed at 90° for about 1 week and after an active range of motion should be started (Liow et al. 2002). To do this it is necessary that pain and edema have subsided, and to achieve this purpose, we can implement all the possibilities described in the previous chapter (see articular distal humeral fractures rehabilitation). When fracture healing appears on X-ray, we can dedicate to a more vigorous range of movement (ROM) recovery with passive ROM and stretching exercises if there is the need (usually near full ROM is achieved 4–5 weeks after trauma). When pain is under control and ROM restored enough, we even begin muscle strengthening recovery. In our clinical practice according to the literature, outcomes after conservative treatment are satisfactory (Shore et al. 2008; Coonrad et al. 2005; Dunning et al. 2001; Armstrong et al. 2000; Szekeres et al. 2008; Herbertsson et al. 2005; Broberg and Morrey 1986; Duckworth et al. 2012b).

If a simple radial head fracture has been synthesized, postoperatively we use a protective brace with elbow flexed to 90° to limit forearm rotation and elbow extension for about 3 weeks, but early ROM is instituted, usually within the first week post-surgery. Flexion is theoretically unlimited although its recovery is gradual because while the elbow flexes, gradually the radio contact humerus increases leading to stress on the synthesis. For this reason we have to be very careful when bending the elbow to avoid causing pain.

So active-assisted or gravity-assisted and active ROM of the elbow and adjacent joints start, as pain and edema decrease. Elbow flexion and extension recovery is performed with forearm neutral rotation. Pronation and supination are performed with the elbow flexed at 90° because between flexion angles of 0° and 45°, the anterolateral portion of the radial head bears a great axial stress. We must be careful not to place stress on the synthesis during the pronation of the radial head for its posterior translation.

We usually have to wait for about 1 month before starting passive ROM, when the fracture has become stable and is at least at an early healing stage, as evident on X-ray (Fig. 13.8a, b). The same applies to stretching and manual therapy useful to decrease residual pain or muscle spasm and increase collagen or muscular tissue elasticity and therefore range of motion. Quite often it is necessary to recover full extension and supination which are lacking. Modalities (such as heat) or manual therapy can be useful to prepare the joint for stretching or mobilization (Mulligan or Maitland). In case of elbow instability with or without radial head excision, avoid any elbow joint mobilizations.

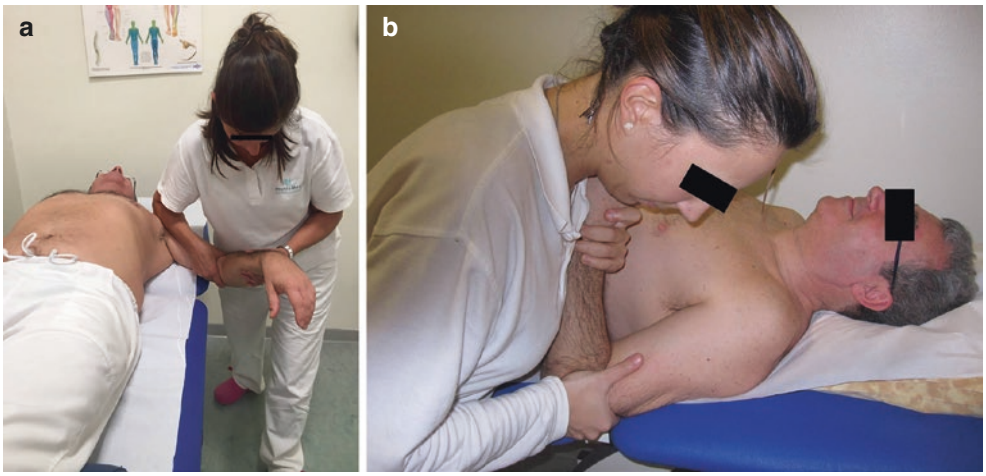


Fig. 13.8 (**a**, **b**) Passive elbow ROM recovery in 1 month postsurgical patient after a complex radial head fracture synthesis toward extension (**a**) and flexion (**b**). The therapist, in both cases, uses the thrust of both the proximal gripping hand to the elbow and of his whole body to mobilize it

Muscle strengthening of the wrist, shoulder, and scapular muscles (Fig. 13.9a–f) can start immediately after surgery but only after 3–4 weeks for the forearm and in a progressive way and above all, for the flexor-pronator muscles (Fig. 13.10). Their reinforcement is useful because they act as dynamic valgus elbow stabilizers, but muscular recruitment generates forces through the radial head that have not to be too strong. For strengthening against resistance, we have to wait about 6 weeks and start using "safe positions" as described for active ROM. At the same time we can even gradually increase the reinforcement of all upper limb, scapula\thoracic, and core muscles. The progression of rehabilitation is the same as that already described for the distal humeral fractures.

In case of radial head complex fractures, the ligament- or bone-associated injuries and their treatment influence the planning and progression of rehabilitation, so this information is of fundamental importance to be reported. Usually patients wear a hinged brace that allows the movement in a safe arc established by the surgeon and avoid valgus and varus stress on the joint. The brace is used continuously for 3–4 weeks, and it is discharged only when performing the exercises assigned. In the brace the elbow is flexed at 90°, but forearm rotation depends on ligament health and instability pattern.

In case of posterolateral instability due to fracture or if the lateral collateral ligament (LCL) is injured or sutured, the forearm will be in pronation and vice versa for an anteromedial instability or medial collateral ligament injury for 4–6 weeks. If both ligaments are injured or repaired, the forearm will be in neutral position. The same position will be kept during the active exercises. Extension will be gained slowly, and the full range is allowed from the 4th week. Prono-supination is performed with elbow flexed to 90°. To protect the LCL patient has to avoid shoulder abduction and external rotation because the varus stress on the elbow can interfere with LCL healing in addition to being a source of pain for the patient.

If a coronoid fracture is associated, elbow splint is blocked over 60 ° of extension and then 10° per week are added. The last 30° of extension are not allowed for 4 weeks. If an olecranon fracture is associated, both full active and passive flexion beyond 90° are avoided, likewise active extension to protect fixation preventing triceps tendon muscle traction for about 4 weeks. This is our behavior unless it is the surgeon that allows to modify the program due to a stable surgical synthesis (e.g., plate, screw, and wire or cerclage). In case of radial head replacement, elbow joints were rested in a 60° flexion position for 3 weeks followed by rehabilitation (Gao et al. 2013).

After radial head excision the elbow has a high potential for instability in valgus and axial directions. For this reason the muscle strengthening program is very important to compensate instability.

So, even in case of complex fractures, active-assisted ROM is begun early, at about 10–14 days after surgery, but in the safe arc defined by the surgeon and with the necessary precautions as stated before. Elbow muscle isometric reinforcement in stable position begins 4 weeks post-surgery, but if a stable position cannot be ensured, it is delayed even to 6–8 weeks. Reinforcement against resistance is allowed after 8–12 weeks according to the stability that has been obtained (Figs. 13.11a, b and 13.12). For wrist, shoulder, and scapular-thoracic muscles, isometric work can start immediately post-surgery according to patient tolerance. Usually the patients can gradually resume their activities after 3–4 months after surgery (Bano and Kahlon 2006).

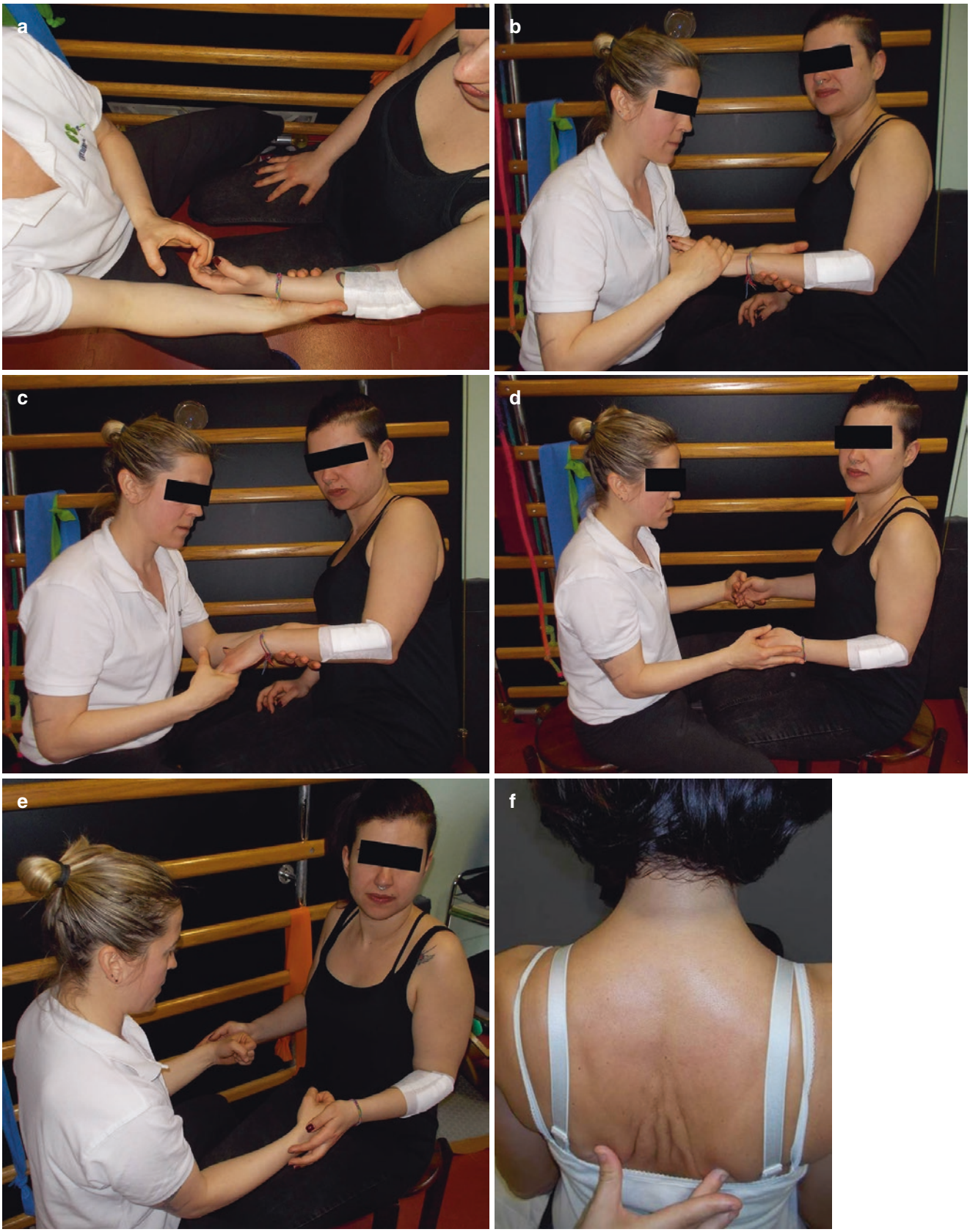


Fig. 13.9 (**a**–**f**) Examples of finger (**a**), wrist (**b**, **c**), shoulder (**d**, **e**), and scapular (**f**) light isometric muscle strengthening exercises

Indomethacin can be used for 3 weeks following surgery, 25 mg twice daily, as prophylaxis against heterotopic ossification, although evidence of efficacy is weak.

Radiation at 700 cGy can be used within 72 h of surgery following the excision of heterotopic ossifications rather than for primary prevention.

Radiographic evaluation will help to determine when bone union is sufficient to allow passive ROM recovery, joint mobilization or stretching, typically at 6 weeks (Szekeres et al. 2008). Joint mobilization is contraindicated in case of unstable elbow, radial head excision, or arthroplasty (see Rehabilitation Highlights at the end).

13.17 The Decision-Making Process

Many factors should be considered in the decision-making process: the characteristics of the radial head fracture (including fragment number, displacement, articular surface involvement, and bone quality) influence the treatment. It is also important to establish the presence of associated ligamentous injuries (medial and lateral) or associated coronoid fracture.

The following algorithm is useful for the surgical process decision between radial head reduction and replacement and ligaments repair (Table 13.1).



Fig. 13.10 Example of pronator mass muscle isometric reinforcement



Fig. 13.12 Example of pronator mass muscle reinforcement against resistance

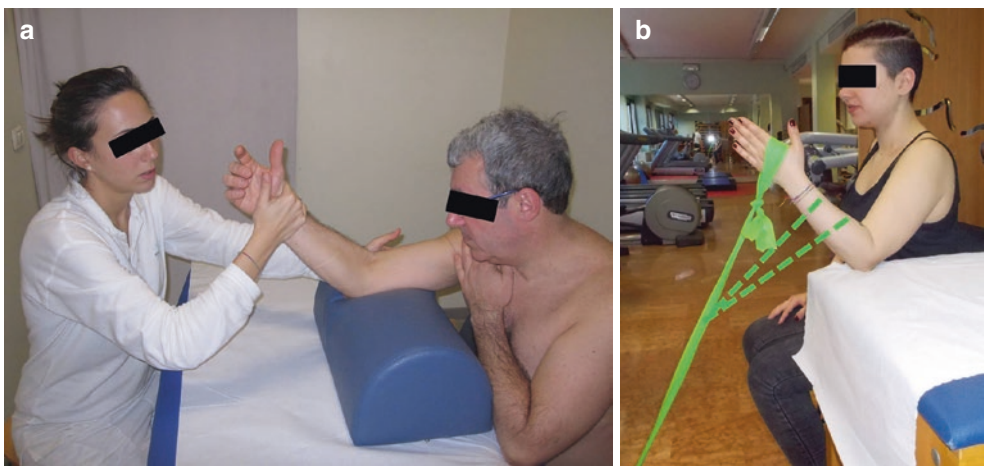
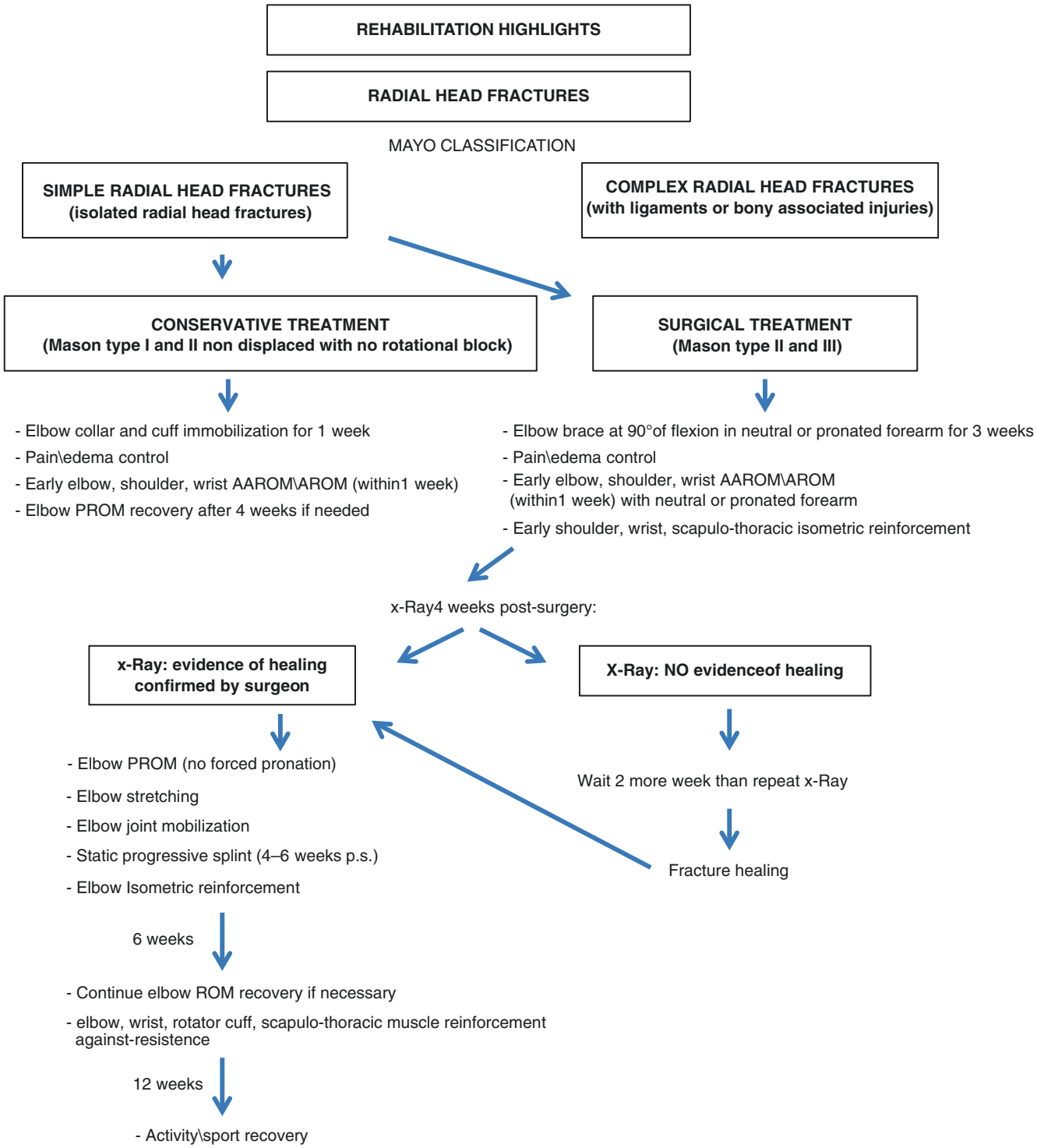
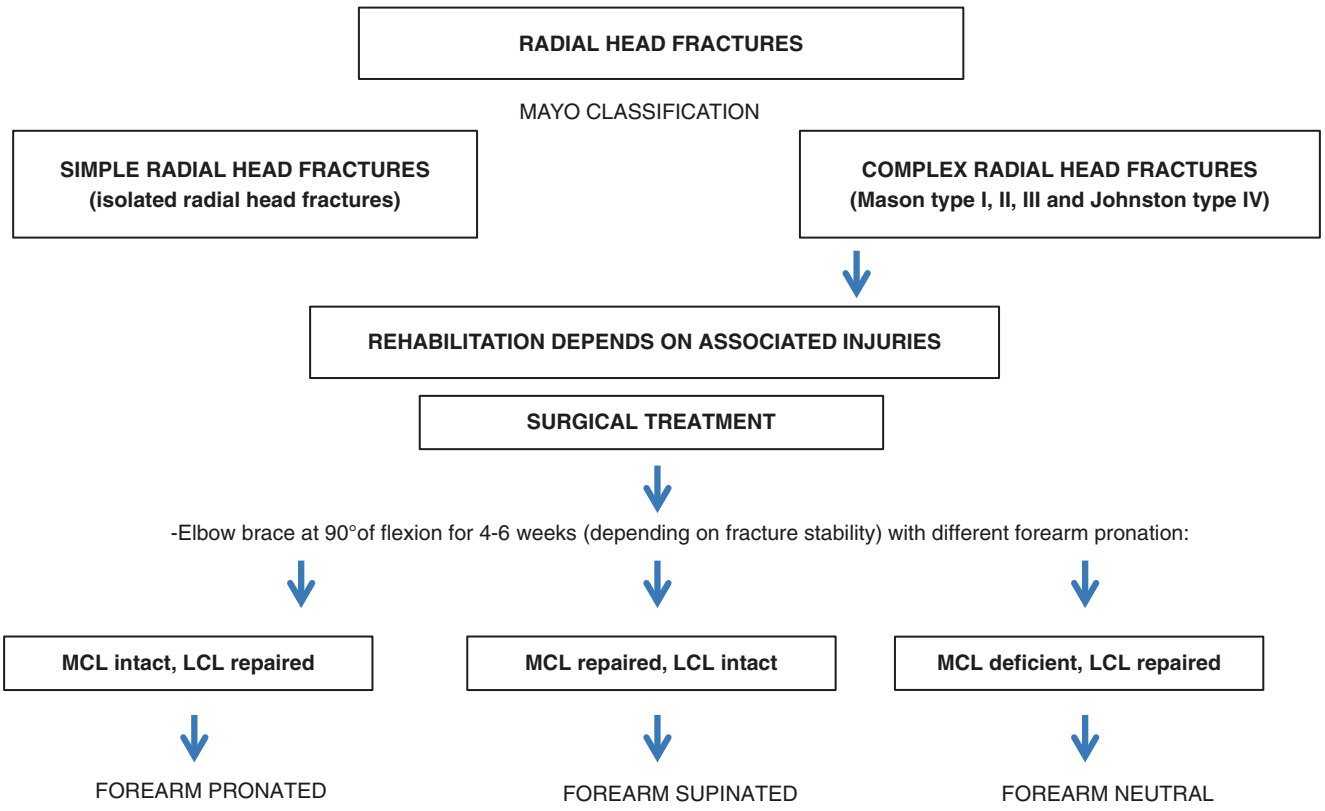


Fig. 13.11 (**a**, **b**) Examples of biceps muscle reinforcement against resistance. Since in this second case (**b**), resistance is placed progressively toward the patient's hand, so that the radial lever is extended, this exercise (and similar ones) will be reserved for a gradually more advanced stage of the biceps muscle reinforcement program


REHABILITATION HIGHLIGHTS
RADIAL HEAD FRACTURES
MAYO CLASSIFICATION
SIMPLE RADIAL HEAD FRACTURES (isolated radial head fractures)
COMPLEX RADIAL HEAD FRACTURES (with ligaments or bony associated injuries)
CONSERVATIVE TREATMENT (Mason type I and II non displaced with no rotational block)
SURGICAL TREATMENT (Mason type II and III)
- Elbow collar and cuff immobilization for 1 week
- Pain\edema control
- Early elbow, shoulder, wrist AAROM\AROM (within1 week)
- Elbow PROM recovery after 4 weeks if needed
- Elbow brace at 90°of flexion in neutral or pronated forearm for 3 weeks
- Pain\edema control
- Early elbow, shoulder, wrist AAROM\AROM (within1 week) with neutral or pronated forearm
- Early shoulder, wrist, scapulo-thoracic isometric reinforcement
x-Ray4 weeks post-surgery:
x-Ray: evidence of healing confirmed by surgeon
X-Ray: NO evidenceof healing
- Elbow PROM (no forced pronation)
- Elbow stretching
- Elbow joint mobilization
- Static progressive splint (4–6 weeks p.s.)
- Elbow Isometric reinforcement
Wait 2 more week than repeat x-Ray
Fracture healing
6 weeks
- Continue elbow ROM recovery if necessary
- elbow, wrist, rotator cuff, scapulo-thoracic muscle reinforcement against-resistence
12 weeks
- Activity\sport recovery



- Early ligament protected or in safe arc elbow AAROM\AROM (within 10-14 days)
- Early shoulder, wrist AAROM\AROM (within1 week)
- Pain\edema control
- Early shoulder, wrist, scapulo-thoracic isometric reinforcement

x- Ray 4-6 weeks post-surgery:

x-Ray: evidence of healing confirmed by surgeon

- Elbow PROM in safe arc or without stressing repaired ligament
- Isometric elbow reinforcement

8 weeks

- Continue elbow ROM recovery if necessary
- Elbow stretching
- Eventually static progressive splint(4-6 weeks p.s.)

8 -10 weeks

- elbow, wrist, rotator cuff, scapulo-thoracic muscle reinforcement against-resistence

12-16 weeks

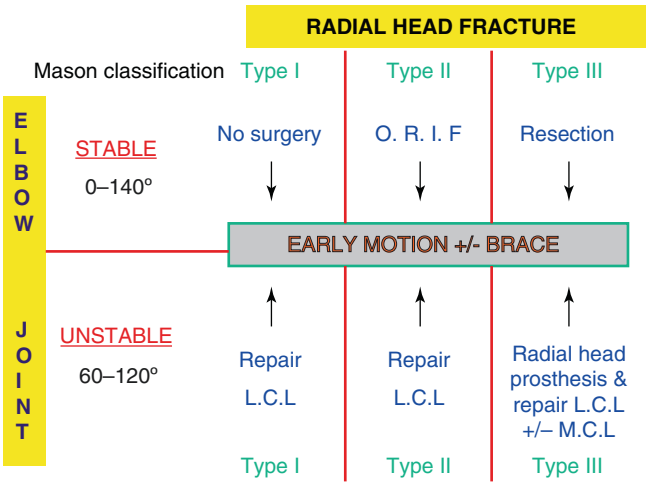
- Activity\sport recovery

X-Ray: NO evidence of healing

Wait 2 more week than repeat x-Ray

Fracture healing

Table 13.1 Many factors should be considered in the decision-making process as the characteristics of the radial head fracture and the presence of associated elbow instability for ligamentous injuries (LCL, lateral collateral ligament; MCL, medial collateral ligament) or associated coronoid fracture



This algorithm is useful for the surgical process decision between radial head reduction and internal fixation (ORIF), replacement and ligaments repair

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Distal Humerus Fractures: The Plating Technique

14

Alessandro Marinelli, Graziano Bettelli, and Roberto Rotini

Distal humerus fractures (DHF) represent 2–6% of all adult fractures (Jupiter and Morrey 1993; Robinson et al. 2003; Rose et al. 1982) and about 10% of all elbow fractures (Aitken et al. 2014). The incidence of DHF has been estimated to be about 6 for every 100,000 people (Robinson et al. 2003), and their number is increasing in frequency as the number of elderly individuals continues to grow (Palvanen et al. 1998).

These injuries are typical in young males with fractures caused by high-energy trauma and in elderly women with fractures caused by a low-energy fall (Robinson et al. 2003).

The AO/ASIF/OTA Classification (Muller et al. 1990) distinguishes 27 different types of fracture, each one with different complexity and specific characteristics (Fig. 14.1). For easy communication in clinical practice, we appreciate the classification proposed by Sanchez-Sotelo (2014), distinguishing four major patterns for distal humerus fractures: each type presents specific peculiarity for surgical approach, fixation technique, and possible indication to elbow replacement (Fig. 14.2).

1. Supraintercondylar column fracture is the most common pattern of distal humerus fractures. The fracture involves the entire distal humerus, going through the columns and the articular surfaces. Inside this group, there are many different degrees of severity, based on the comminution at the articular and supracondylar level.
2. Capitellar and trochlear fractures. This kind of fracture has been discussed in Chap. 20.
3. Low transcondylar fractures, consisting in a single extra-articular fracture, exiting through or below the lateral epicondyle and at the level of or just above the medial epicondyle. These fractures, typical in elderly female patients, present difficulties in fixation, greater in case of distal level of the fracture or marked osteoporosis.
4. Partial articular fracture: the fracture, also defined "unicolumnar," involves a large portion of the articular surface and its adjacent column, usually in a single piece. Fractures of the lateral column are more common than those of the medial column.

Independently of the pattern of fracture, the treatment of DHF is almost always surgical, requiring reduction and internal fixation.

Reviewing the cases treated 35 years ago in our hospital, we can see that similar fractures had been treated in the same period by the same expert trauma surgeon, using different hardware and different reconstruction strategies (Fig. 14.3). It is evident that at that time the fixation technique was not yet standardized and in the absence of a reproducible technique, art, experience, and momentary improvisation guided the choice of fixation. In that period good results could be obtained only by the most skilled surgeons. Since then, we can see how dramatic changes have occurred in the treatment of distal humerus fractures. The technique has improved, becoming much more standardized and reproducible, allowing to improve the results and to decrease the complication rate.

We think that five elements have contributed to improve our surgical technique: (1) the systematic use of preoperative CT-scan, (2) a better knowledge and choice of the exposure, (3) the routinely use of double pre-contoured plating technique, (4) the use of principle-based surgical technique, and (5) the selective use of elbow replacement in unfixable fractures.

14.1 Preoperative CT Scan

CT scan, with 2D and 3D reconstruction, is always valuable in distal humerus fracture for a better understanding of the fracture pattern, for the preoperative planning, for the choice of the approach, and for facilitating the comprehension of the reduction and fixation strategy (Fig. 14.4). There

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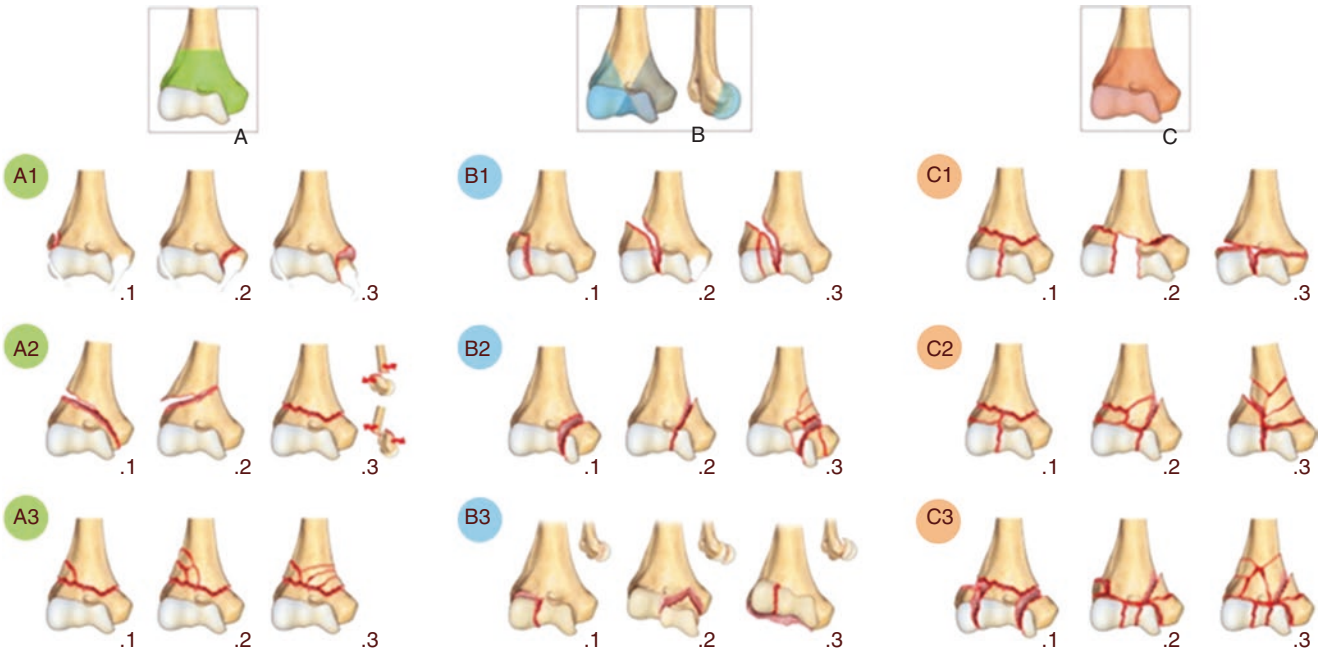


Fig. 14.1 The AO/ASIF/OTA Classification. Type A or extra-articular fracture, type B or partial articular fracture, and type C or complete articular fracture. Each type is further divided in nine patterns based on the localization, number, and comminution of the fractures

are some possible exceptions, like some simple extra-articular fractures or cases with preoperative indication for elbow replacement, where good preoperative X-rays can be enough.

14.2 A Better Knowledge About Exposure

The experience taught us that behind many unsuccessful fixations, there is an inappropriate approach. Even the apparently improvident choice of attempting a mini-invasive fixation in adult patients with a DHF is very often essentially caused by a lack of confidence in the approach, more than a definitive belief about the accuracy of the choice (Fig. 14.5). The difficulty in the approach is justified by the complexity of the elbow anatomy, the proximity of neurovascular structures, and the wide visualization that is necessary to achieve for reducing and stabilizing the fracture. Many surgical approaches have been described in the treatment of distal humerus fractures. In particular, nine of them can be effectively used to treat the different patterns of distal humerus fractures (27 according to AO/ASIF/OTA Classification): olecranon osteotomy, triceps on (or triceps preserving), triceps splitting, triceps-reflecting anconeus pedicle (TRAP), tongue, Bryan-Morrey, Kocher approach, Hotchkiss approach, and posterolateral extensile exposure. Each approach presents specific indications and particular limits (Marinelli et al. 2015). The selection of a surgical approach is dependent on several factors. Surgeon's experience and preferences, fracture pattern, degree of articular involvement, and associated soft tissue injury, whatever intraoperative conversion to arthroplasty is contemplated, are all elements to consider in the choice of the approach. For these reasons no single approach can be considered optimal for the treatment of all the different patterns of distal humerus fractures. The algorithm we present, that is, the summary of our behavior adopted in the last years, can help the surgeon in deciding among so many different approaches, guiding the choice to the more appropriate exposure for the specific pattern of fracture (Fig. 14.6).

Simple extra-articular fracture (A2–A3 types of the AO/ASIF/OTA Classification) may be properly exposed using the triceps on approach, without interrupting the extensor mechanism. The triceps-on approach can be also used in case of simple supraintercondylar column fracture, converting the approach in TRAP or olecranon osteotomy in case of difficulties to obtain a greater articular exposure. The triceps-on approach is also the preferred approach to treat cases with total elbow arthroplasty, using the window created by the fragments removed.

Triceps-splitting approach can be used in case of simple supraintercondylar column fracture. The limited exposure of the joint makes this approach not indicated to treat complex distal humerus fractures.

Olecranon osteotomy approach offers the maximum exposure, and it can be considered the gold standard in elbow trauma for the treatment of complex intra-articular fractures of the distal humerus.



Fig. 14.2 Four major patterns for distal humerus fractures: (*upper left*) supraintercondylar column fracture, (*upper right*) capitellar and trochlear fractures, (*lower left*) low transcondylar fracture, (*lower right*) partial articular fracture

14.3 The Use of Double Pre-contoured Plating Technique

The use of a double plate, one for each column, introduced by AO/ASIF/OTA group in the early 1980s (Jupiter et al. 1985), has become the standard treatment for the internal fixation, substituting the oldest fixation performed only with screws, wires, or a single plate. Another step forward, in the early 2000s, was the introduction of anatomically pre-contoured plates (O'Driscoll 2004; O'Driscoll 2005) that progressively substituted the oldest 1/3 tubular plates and the reconstruction plates, contributing to further improve technique and outcomes of internal fixation.

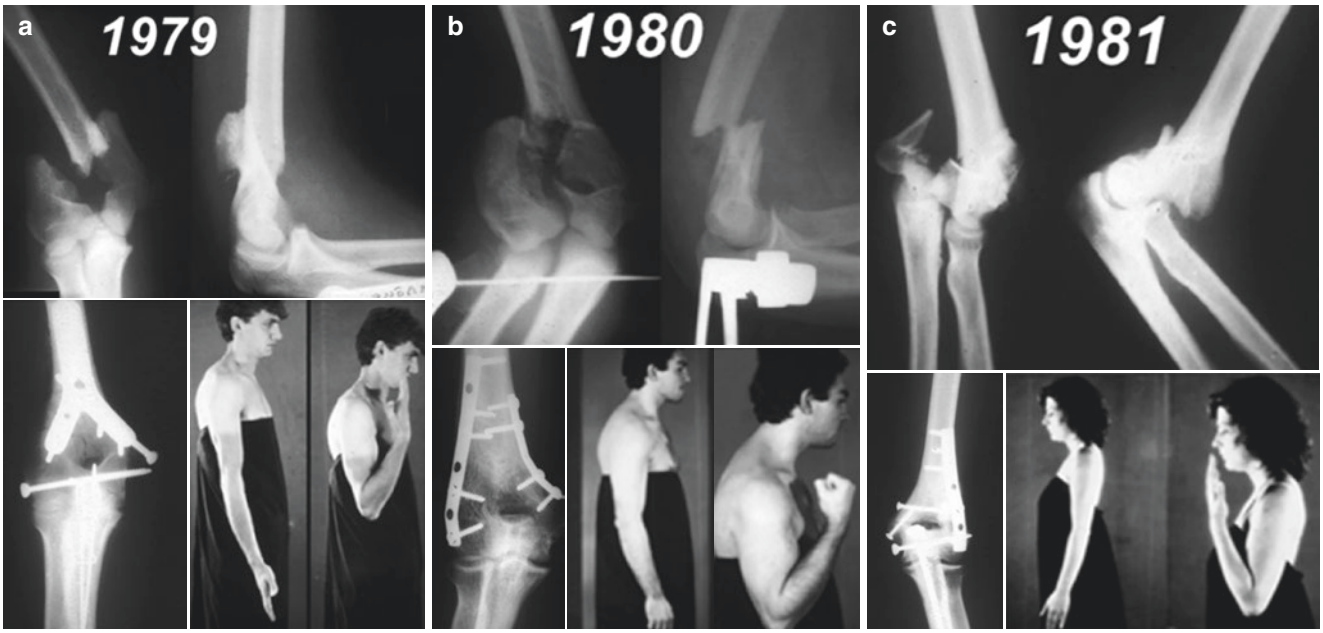


Fig. 14.3 Three cases of supraintercondylar column fracture treated in the early 1980s using three different surgical techniques: (**a**) Y-plates and screw out of the plate, (**b**) two molded condylar plates, (**c**) one posterior plate and screws out of the plate. Excellent clinical results were obtained in each case. (Courtesy of Professor Gianfranco Zinghi)

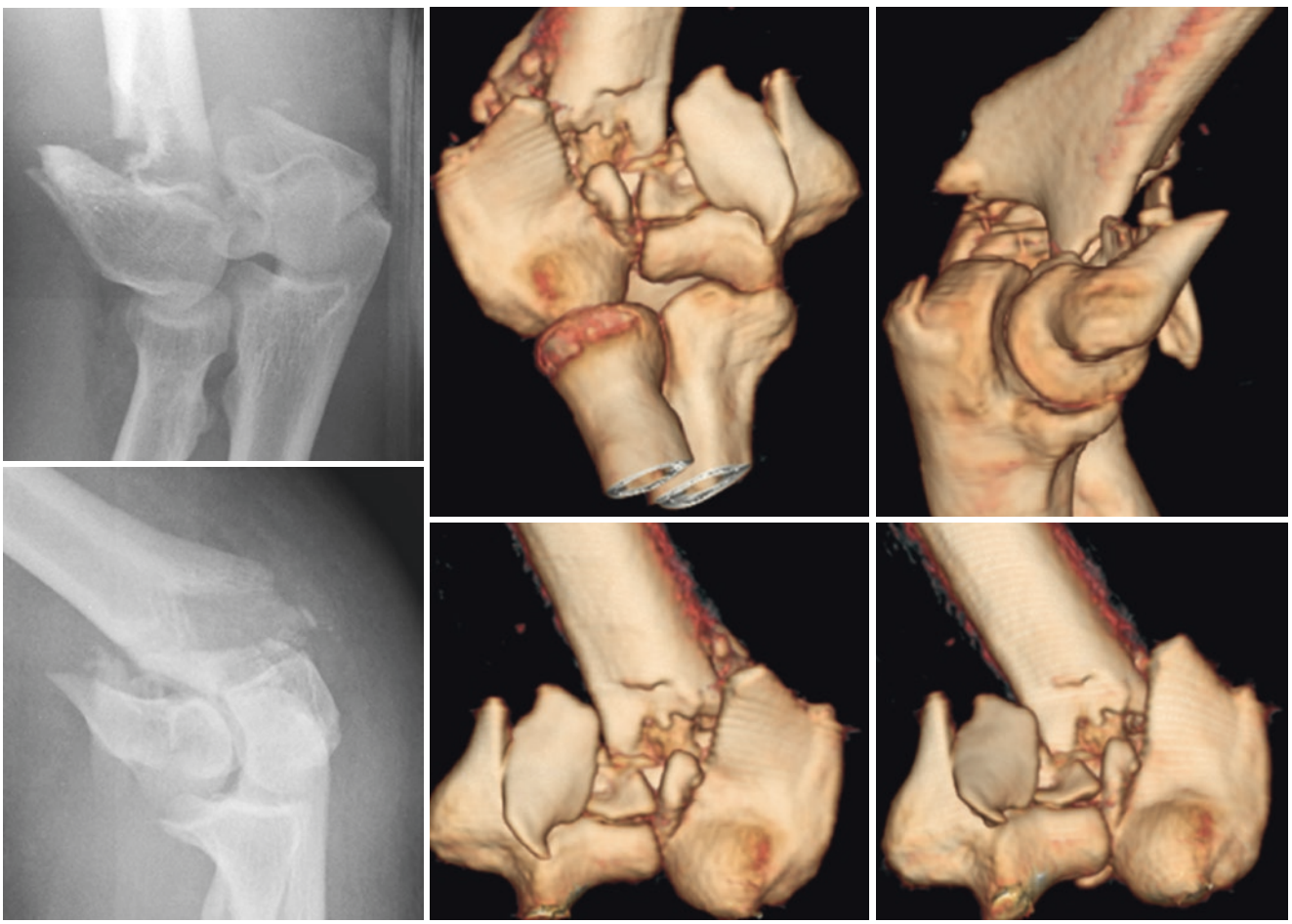


Fig. 14.4 X-rays and CT scan of a supraintercondylar column fracture (C3.2 AO/ASIF/OTA Classification). The CT scan, implemented by 2D and 3D reconstructions, allows a better understanding of the fracture complexity, showing the number, dislocation, and comminution of the fragments

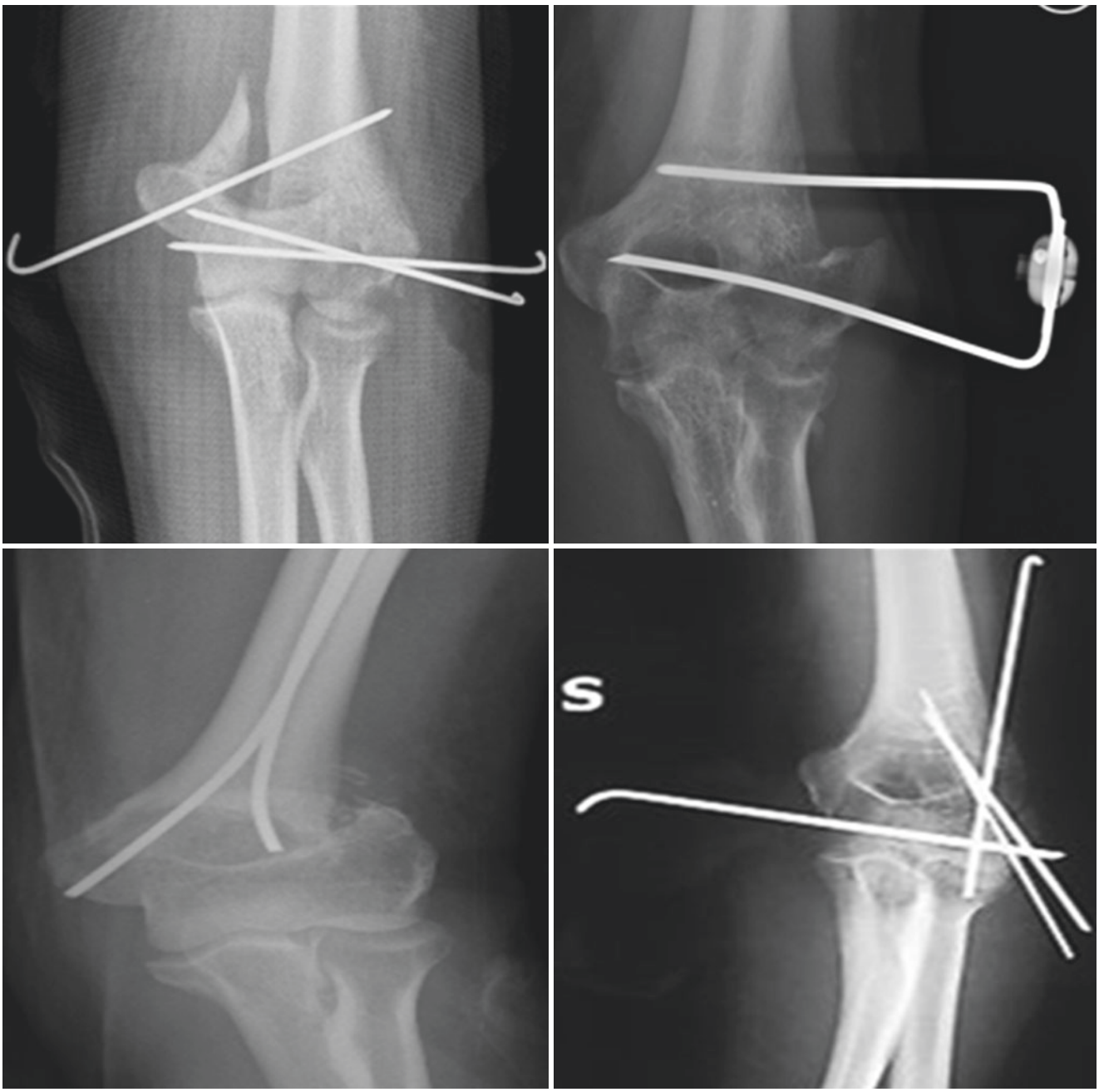


Fig. 14.5 Failed mini-invasive fixation for distal humerus fractures in adult patients. Often the lack of confidence in the approach affects the choice of the fixation technique

The pre-contoured plates, initially introduced by Mayo Clinic, and today supplied by several companies, have anatomical shapes that well fit the contour of distal humerus. Especially in complex fractures, they are very helpful in guiding the anatomic reconstruction of the distal part of the humerus, reducing the possible alignment mistakes of the articular surface on the sagittal and coronal plane. Moreover, not having to anatomically bend the straight plates permits to save time in the operating room and to use more rigid plates not wasted by intraoperative bending. These plates improve the fixation technique, allowing with oblong hole to perform compression on the fracture, optimizing the number and the direction of the screws in the distal humeral fragment, presenting the possibility of locking screw fixation, useful especially in the distal fragment in osteoporotic or comminuted bone (Sanchez-Sotelo 2014; Sanchez-Sotelo et al. 2007). The slim design and the polished surface, especially around the epicondyles, limit the irritation of overlying soft tissues, permitting in the majority of cases not to have to remove the hardwares.

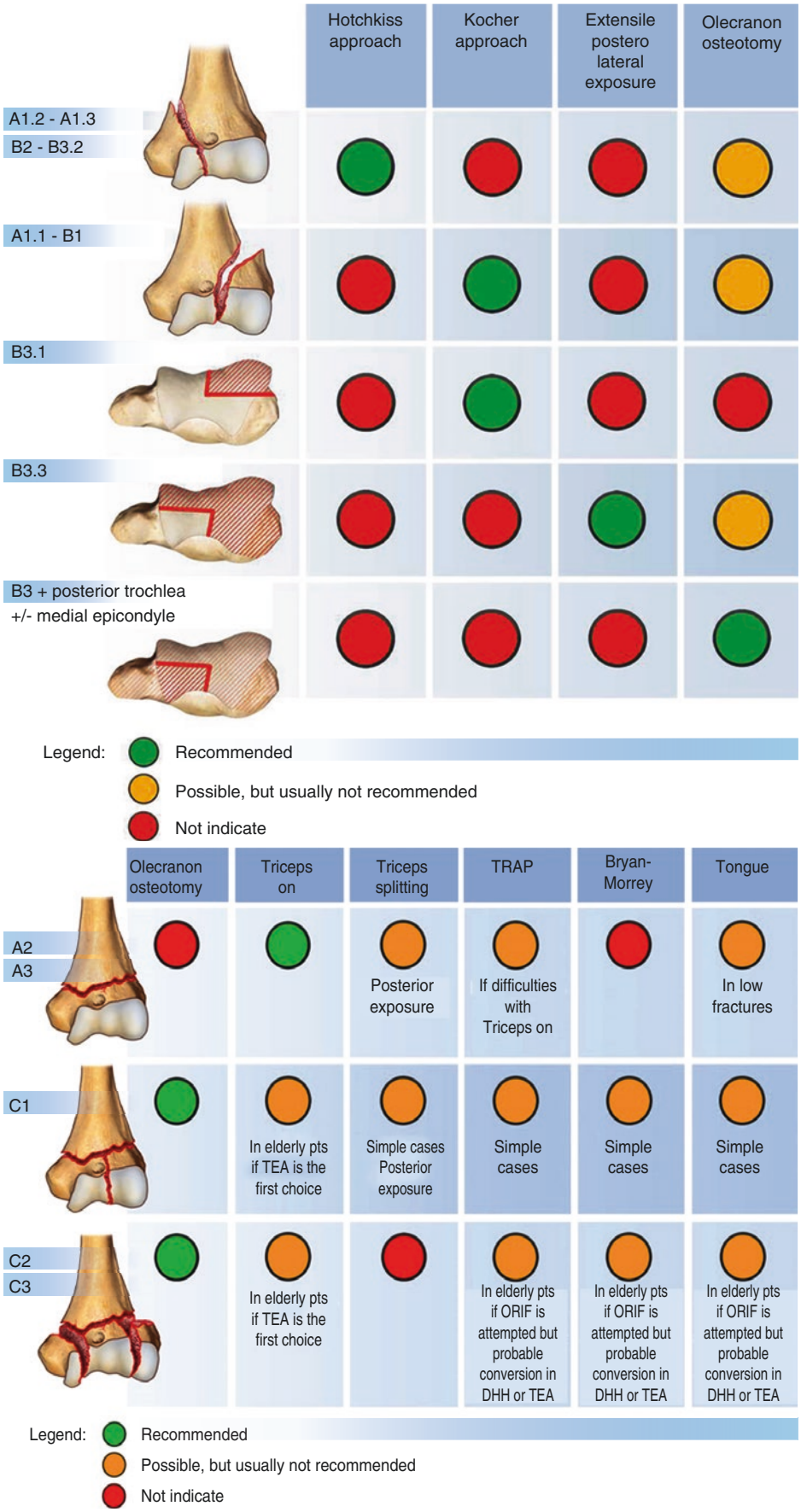


Fig. 14.6 Indications for surgical approaches based on the AO/ASIF/OTA Classification of fracture patterns. The approach is indicated as recommended (*green sign*), possible but usually not recommended (*yellow sign*), and not indicated (*red sign*). (**a**) Algorithm for partial articular fractures and capitellar and trochlear fractures. (**b**) Algorithm for supraintercondylar column fractures and low transcondylar fractures

The double plating technique can be used with two different configurations, according to two different philosophies:

1. The orthogonal technique, otherwise known as 90–90 plating or perpendicular plating and supported by the AO/ASIF/OTA group, consists in placing two plates at a 90° angle to one another, with the lateral plate placed on the coronal plane along the posterior aspect of the lateral column and the medial plate applied on the medial ridge (Fig. 14.7).
2. The parallel plating technique consists in applying the plates over the two supracondylar ridges in the sagittal plane (O'Driscoll 2005; Sanchez-Sotelo et al. 2007). Even if we define them as parallel, each plate is actually rotated slightly one toward the other out of the sagittal plane, such the angle between them is often in the range of 150–160° (Fig. 14.8). This orientation permits to limit the soft tissue detachment on the posterolateral side and to insert bicortical screws from one side to the other of the shaft.



Fig. 14.7 Orthogonal or perpendicular plating technique: it consists in placing two plates at a 90-degree angle to one another, with the lateral column supported by a plate placed on the coronal plane along the posterior aspect of the lateral column and the medial column supported by plate directly applied on the medial ridge



Fig. 14.8 Parallel plating technique: it consists in applying the two plates over the two supracondylar ridges in the sagittal plane, usually slightly rotated one toward the other out of the sagittal plane. This configuration allows the use of long and interlocking screws in the distal part of the humerus and the possibility to apply a compression at the supracondylar level

Several studies have addressed distal humerus fracture fixation comparing plates placed in parallel versus perpendicular configurations. Of the 12 biomechanical studies we identified, six studies demonstrated biomechanical superiority of the parallel-plate configuration (Schemitsch et al. 1994; Self et al. 1995; Arnander et al. 2008; Stoffel et al. 2008; Windolf et al. 2010; Zalavras et al. 2011), four showed similar biomechanical properties between the two groups (Schwartz et al. 2006; Kollias et al. 2010; Got et al. 2012; Koonce et al. 2012), and one demonstrated superiority of perpendicularly placed plates (Jacobson et al. 1997). One study showed mixed results with parallel plates stiffer in extension and perpendicular plates stiffer in flexion (Penzkofer et al. 2010). The wide variations in testing protocols, testing media (cadaver versus sawbones), different fracture patterns, different plate screw manufacturers, and definitions of failure can explain the conflicting results observed.

In two prospective randomized studies (Shin et al. 2010; Lee et al. 2014), no significant differences were recorded

between the two groups. Shin (Shin et al. 2010) presented the perception that a more rigid fixation can be provided by two parallel-plate techniques. Lee (Lee et al. 2014) expressed the opinion that perpendicular configuration is advantageous in cases of coronal shear fractures, with the possibilities of the screws from the posterolateral plate helping to capture coronal fracture involving the capitellum, while the parallel configuration may provide stability at the most distal portion of the humerus and also in the presence of osteoporosis and comminution.

The better stability, especially in complex fractures, obtained by parallel-plate configuration described by most of biomechanical studies and perceived by the clinical experience, can be explained by mechanical evaluations. With parallel-plate configuration, the fragment fixation and the compression at the supracondylar level are achieved and maintained by means of the architectural linkage created by the screws and plates to fix each bony fragment with the whole structure. Moreover, the configuration with plate opposite one to the other allows the use of longer screws in the distal part of the humerus and the possibility to apply a more consistent compression at the supracondylar level compared to the perpendicular-plating configuration.

All things considered, we can affirm that the routinely use of modern pre-contoured double plating technique has improved the results of distal humerus fracture fixation. Plate configuration can be chosen according to the fracture configuration and surgeon preference, and as in most of the factures, orthogonal or parallel dual plating provides equivalent results. The introduction of posterolateral plates allowing screw insertion also on the coronal plate further decreases the differences between the two philosophies (Fig. 14.9). However, most of the mechanical studies and widespread clinical impression support the parallel plating technique for the more complex distal humerus fracture.



Fig. 14.9 Posterolateral plate allowing screw insertion in the distal part of the humerus also in the coronal plane

14.4 The Principle-Based Technique

This surgical technique, proposed in the early 2000s by Shawn O'Driscoll, allows to maximize the effectiveness of the double parallel-plate technique (O'Driscoll 2004; O'Driscoll 2005; Sanchez-Sotelo et al. 2007). Over the last 10 years, following O'Driscoll teachings, we have seen that our surgical procedures have become more reproducible, that the stability of the fixation at the end of the surgery is general such that an intensive rehabilitation program can be started in the immediate postoperative period without fear of hardware failure, and that we have reduced the number of elbow replacements, being able to fix fractures that preoperatively have been thought to be unfixable.

According to the principle-based technique, the overall resistance of the fracture fixation relies not just on the compression between plate and fragments, but actually on the global stability obtained by the whole hardware framework fixation (O'Driscoll 2004; O'Driscoll 2005; Sanchez-Sotelo et al. 2007). To achieve that, the two mainstays are:

1. Maximize fixation in the distal fragment.
2. Apply a true compression at the supracondylar level.

The following are the eight commands to follow:

1. Each screw should pass through a plate.
2. Each screw should engage a fragment on the opposite side that is also fixed to a plate.
3. An adequate number of screws should be placed in the distal fragments.
4. Each screw should be as long as possible.
5. Each screw should engage as many articular fragments as possible.
6. The screws should lock together by interdigitation, thereby creating a fixed angle structure and linking the columns together.
7. Plates should be applied such that compression is achieved at the supracondylar level for both columns.
8. Plates used must be strong enough and stiff enough to resist breaking or bending before union occurs at the supracondylar level.

Locking screws can enhance the fixation in comminuted or osteoporotic bone, especially in the articular part of the fracture, reducing the risk of screw loosening and mobilization. The combined use of clamps, strong and slightly undercontoured plates, the dynamic compression holes, and, in selected cases, the metaphyseal shortening allow a rigid linkage and compression between the distal segment and the shaft (O'Driscoll 2004; O'Driscoll 2005; Sanchez-Sotelo et al. 2007). Using the supracondylar shortening osteotomy allows to make a good fixation in cases that would be addressed otherwise with a total elbow replacement (Fig. 14.10).

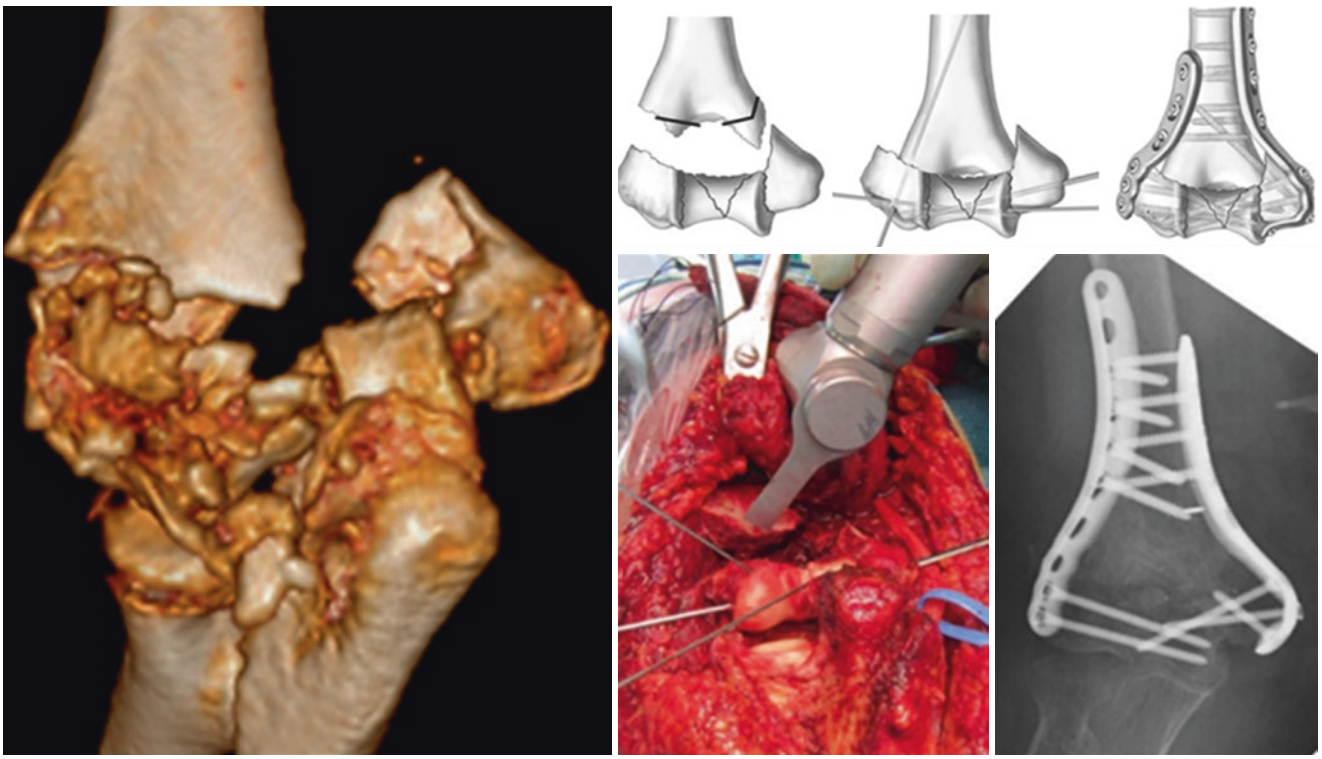


Fig. 14.10 In case of severe comminution at the metaphyseal level, the supracondylar shortening osteotomy allows to apply compression between articular and metaphyseal fragments in order to maximize the contact area at the supracondylar level

14.5 Elbow Replacement

Despite the improvement of internal fixation, there remains a subset of fractures that are difficult to reconstruct for their poor bone quality and articular comminution. In these cases, the internal fixation should not be pursued at every cost, especially in elderly patients. These cases are better treated with elbow arthroplasty that can be performed with a total elbow implant (total elbow arthroplasty, TEA) or with substitution of only the humeral part (distal humerus hemi-arthroplasty, DHH) (Rotini et al. 2015) (Fig. 14.11). There are many reports showing good short- and mid-term results for range of motion and pain after TEA in distal humerus fractures (Kamineni and Morrey 2004; McKee et al. 2009). However, aseptic loosening, polyethylene wear, osteolysis, peri-prosthetic fracture, and infection are possible serious complications. The DHH has been conceived to provide the advantages of an arthroplasty, reducing its complications related to the prosthesis linkage, to the polyethylene, and to the ulnar component. Conversely, DHH may be associated with chondral wear of the greater sigmoid notch and of the radial head, or instability, because of its unlinked nature. Indications for DHH are comminuted intra-articular fractures where an ORIF is not technically feasible and the patient is not suitable for a TEA because of the active age and functional needs. Moreover, indication for a DHH requires a stable fixation of the medial and lateral humeral columns with the presence of efficient medial and lateral collateral ligaments and integrity of the coronoid and of the radial head. The market offers convertible prosthetic systems, allowing the conversion from DHH to TEA leaving the humeral stem in place, if overtime complications (like chondral wear or instability) occur. In the literature for acute fractures, only little more than 100 cases of DHH have been reported until now (Smith et al. 2016). Due to the current limited experience, the role of this type of implant needs to be better defined in the future.

Conclusions

Despite the remarkable improvements in the surgical treatment of distal humerus fractures, they still remain one of the most demanding procedures in elbow surgery. Every effort should be made to maximize the accuracy of the first surgical treatment, because if complications occur, like malunion, non-union, or avascular necrosis, the possibility of salvage procedures is limited.

The key to a successful treatment of these fractures is obtaining anatomic reduction of the articular part and a stable fixation with a true compression between the diaphyseal and metaphyseal fragments. This allows a relatively low rate of necrosis or non-union even in comminuted fractures and the possibility to allow an early range of motion.

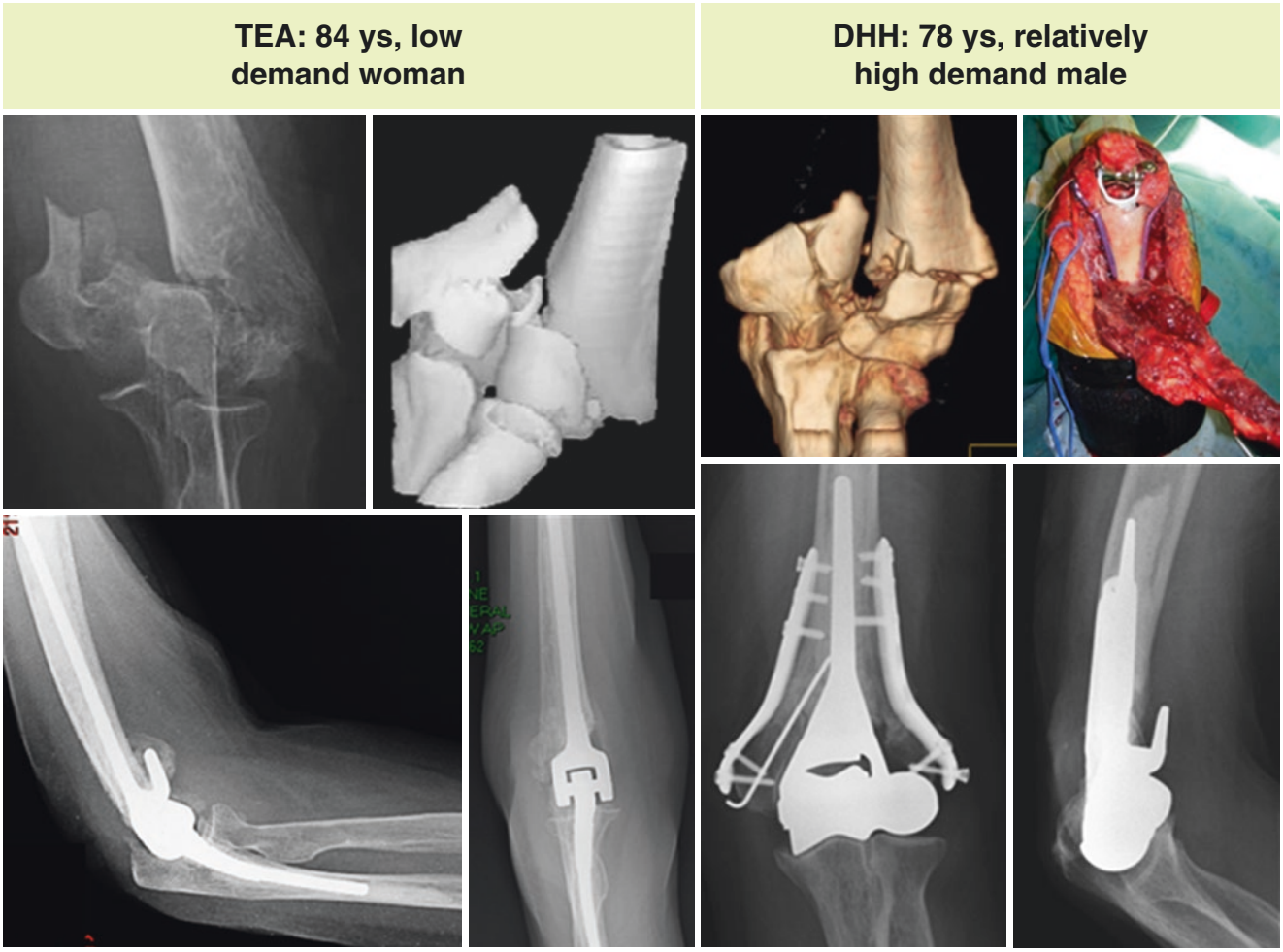


Fig. 14.11 Elbow replacement can be performed in older patients especially if the fracture cannot be effectively reduced and fixed. Total elbow prosthesis is indicated in low-demand patients. Distal humerus hemi-arthroplasty can be used in younger and moderate demanding patients, with the aim to reduce the complications of TEA, related to the prosthesis linkage, to the polyethylene, and to the ulnar component

We can attribute to five elements the improvements in the technique and in outcomes observed in our clinical practice over the last 10 years:

1. The preoperative evaluation with a CT scan, allowing a better understanding of the fracture pattern, improving the choice of the surgical approach and of the reduction technique, and improving our preoperative ability to predict the possibility to fix or replace the joint.
2. Improved ability in performing and managing the nine possible approaches to the distal humerus, choosing the approach on the basis of the fracture pattern more than of our personal preference.
3. Routine use of double pre-contoured plating technique. These plates guide the anatomical reduction and allow a more stable fixation, optimizing the number and the direction of the screws in the distal fragment. Widely shared clinical impressions and some biomechanical studies support the concept that the parallel-plate technique allows to achieve a better stability in cases of low transcondylar fractures or severely comminuted fractures.
4. The principle-based technique is a fundamental guide in performing a reproducible technique and allows the surgeon to obtain a relative confidence in treating these fractures, also if few cases are treated each year. Even if it is not always possible to strictly follow all the recommendations, the advantages in respecting the technique are so evident that, in our experience, we try to follow it as closer as possible. Applying compression to the metaphyseal fragments, using the supracondylar shortening osteotomy in case of comminution in order to maximize the contact area at the supracondylar level, and using the locking screws in osteoporotic patients allowed us to improve the percentage of cases treated with fixation, reducing the number of intraoperative conversion in elbow replacements.
5. The selective use of elbow replacement for cases not treatable with an effective fixation. The prosthesis should be considered a great and effective alternative to a suboptimal fixation for low-demand or elderly patients.

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Capitellar and Trochlear Fracture: Treatment and Rehabilitation

15

Alessandro Marinelli, Enrico Guerra, Graziano Bettelli, and Susanna Stignani Kantar

15.1 Introduction

Coronal shear fractures of the distal humerus involve the capitellum, the trochlea, or a combination of both. They are relatively uncommon, representing 6% of distal humerus fractures and 1% of all elbow fractures (Bryan and Morrey 1985). However, in the last years, we have noticed a progressive increase of their incidence, moreover in adult and elderly female patients, making this kind of fractures more common than in the past in our practice. Most capitellum fractures are the result of a fall on an outstretched hand with the elbow partially flexed and the forearm partially pronated. This mechanism causes a direct axial load from the radial head to the capitellum. Alternatively, the fracture can occur during the reduction phase of a posterolateral rotatory dislocation for the impact of the radial head and coronoid against the capitellum and trochlea.

Different names for this type of fractures have been proposed over the last 30 years (Table 15.1). The evolution of the name reflects the progressive improvement of our understanding about them.

At first they were defined as "fractures of the only capitellum" and were classified according to Bryan and Morrey (1985) in three types: type 1 fracture, so-called Hahn-Steinthal fractures, that consists of a single and large hemispherical osseous fragment involving the entire capitellum with a good subchondral bone, type 2 (Kocher-Lorenz) which consists of an osteochondral fracture with a minimal subchondral bone, and type 3 consisting of a comminuted or compression fracture of the capitellum (Fig. 15.1).

Then, observing that frequently also the trochlea is involved, McKee et al. (1996) added a fourth type to the previous classification, and these fractures were named "coronal shear fractures."

Some years later, Ring et al. (2003) defined them "articular fractures of the distal humerus" noting that these lesions often not only are coronal shear fractures of the capitellum and trochlea but frequently involve the lateral epicondyle, the lateral column, the posterior part of the trochlea, and the medial epicondyle as well, in a subsequent progression of severity caused by the trauma.

To emphasize the important concept that isolated capitellar fractures, seen on plain X-ray, are uncommon and most often they present an involvement at least of the lateral trochlea, Ring (2007) proposed the name of "apparent capitellar fracture." Later Davies and Stanley (2006) called these fractures predominantly articular fractures.

In 2006 Dubberley et al. (2006) proposed the name of "capitellar and trochlea fractures" and a new classification system that identifies as prognostic factors the extension of the fracture on the coronal plane and the presence of fragmentation and of posterior comminution.

At the moment, the Dubberley and AO/ASIF classifications are the most accepted.

According to the AO/ASIF classification, these fractures are grouped as B3 (distal aspect of the humerus, partial artic-

Table 15.1 Capitellar and trochlear fractures: different names proposed over the last 30 years

Fractures of the capitellum	Bryan and Morrey (1985)
Coronal shear fractures	McKee et al. (1996)
Articular fractures of the distal humerus	Ring et al. (2003)
Predominantly articular fractures	Davies and Stanley (2006)
Capitellar and trochlear fractures	Dubberley et al. (2006)
Apparent capitellar fractures	Ring (2007)

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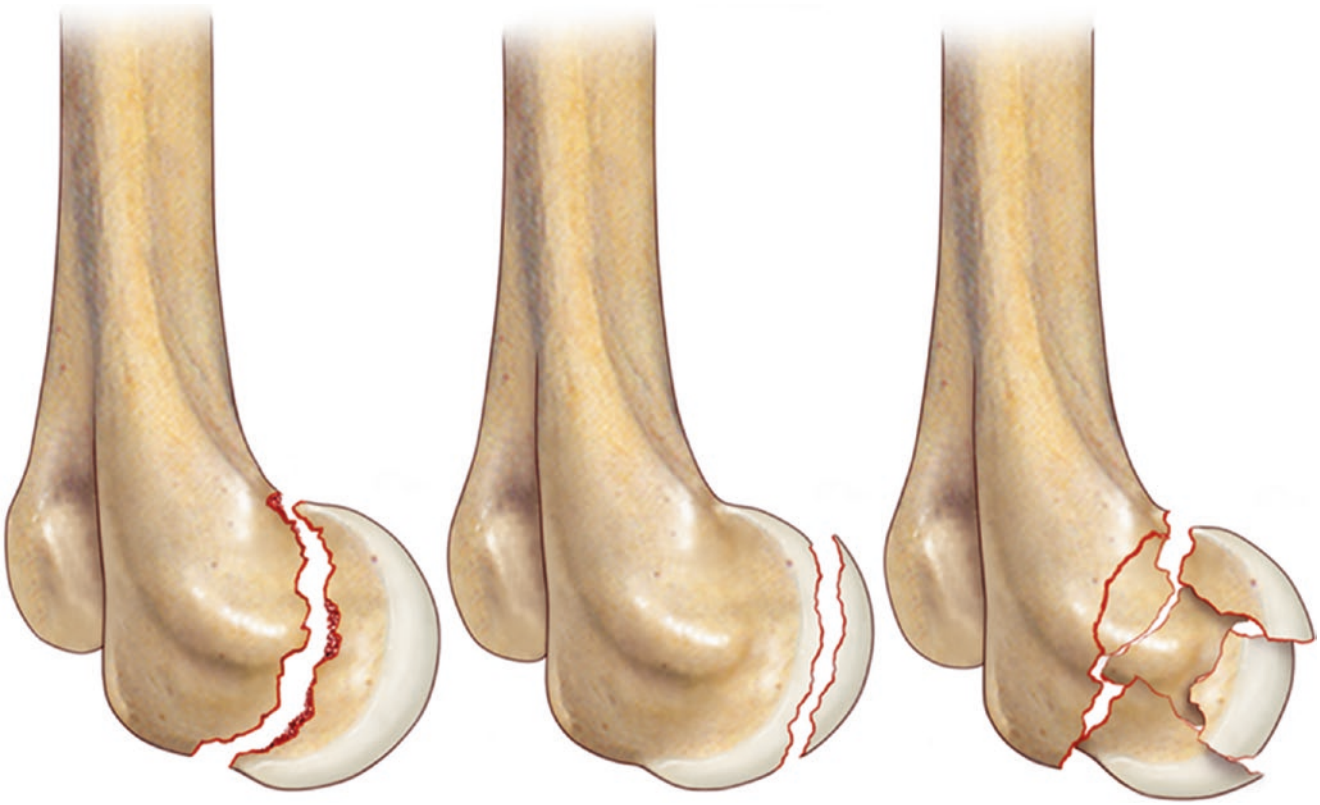


Fig. 15.1 Broberg-Morrey classification of capitellar fractures. Type 1 or "Hahn-Steinthal" fracture on the left, type 2 or "Kocher-Lorenz" fracture at the core, type 3 comminuted fracture on the right

ular, and frontal), with B3.1 indicating capitellar fractures, B3.2 trochlear fractures, and B3.3 capitellar and trochlear fractures (Bandi and Muller 1979).

Recently, it became clear that isolated fractures of the capitellum are rare and that in almost 80% of the cases the capitellar fracture involves a part of the trochlea (Ring et al. 2003; Dubberley et al. 2006; Watts et al. 2007; Guitton et al. 2009). A lateral collateral ligament injury is associated in up to 40%, and a radial head fracture is reported from 10 to 30% of cases (Dubberley et al. 2006; Mighell et al. 2010; Heck et al. 2012).

15.2 Diagnosis

On plain X-ray, mostly in the anteroposterior views, these types of fractures can be difficult to identify. For this reason in the emergency department, a high index of suspicion is needed to avoid missing this kind of fractures.

When the fracture involves the capitellum with some extension of the trochlea, a pathognomonic radiographic feature can be seen on the lateral view: this is the so-called double-arc sign, and it is formed by the subchondral bone of the capitellum and of the lateral trochlear ridge, typically rotated and displaced in a superior direction.

CT scan is important for a correct comprehension of the fracture and for surgical planning. It is important on the CT study to look for the involvement of the capitellum and the trochlea, of the columns, and of the posterior trochlea and the presence of posterior impaction or comminution that has important implications for surgical fixation, rehabilitation, and prognosis. Moreover CT scan can show more clearly associated lesions, like radial head or proximal ulnar fractures.

15.3 Treatment

Several methods have been described for the treatment of capitellum and trochlea fracture, including conservative treatment, simple excision, open reduction and internal fixation (ORIF), arthroscopic reduction and internal fixation (ARIF), and elbow arthroplasty (total elbow or distal humerus hemiarthroplasty). It is nowadays well known that conservative treatment of displaced capitellar and trochlear fracture leads invariably to poor results and it should be considered only in selected cases (Fig. 15.2).

If the severity of the comminution of the capitellum precludes any attempt of ORIF, fragment excision, performed with open technique or arthroscopically, can be a reasonable option of elbow salvage.

In this case it is important to remember that the capitellum does not contribute significantly to the ulnohumeral joint stability when all the other stabilizers are intact. On the



Fig. 15.2 Intrinsic elbow stiffness after conservative treatment of a distal humerus articular fracture. The CT scan image shows evident malunion with joint incongruency. The treatment of these inveterate cases is challenging

contrary, all the trochlea is necessary for a normal elbow kinematics, even when all the other stabilizers are intact (Sabo et al. 2010).

Thanks to the great improvement we had in surgical approaches and fixation techniques, nowadays, it is possible to perform ORIF in the majority of the cases.

The first choice option is the fixation with screws. However, if the fragments do not present an adequate dimension or in cases of posterior comminution (Dubberley type B fractures), it is necessary to have different fixation devices available, to evaluate case by case, like Kirschner wires, resorbable pins, anatomical plates, and external

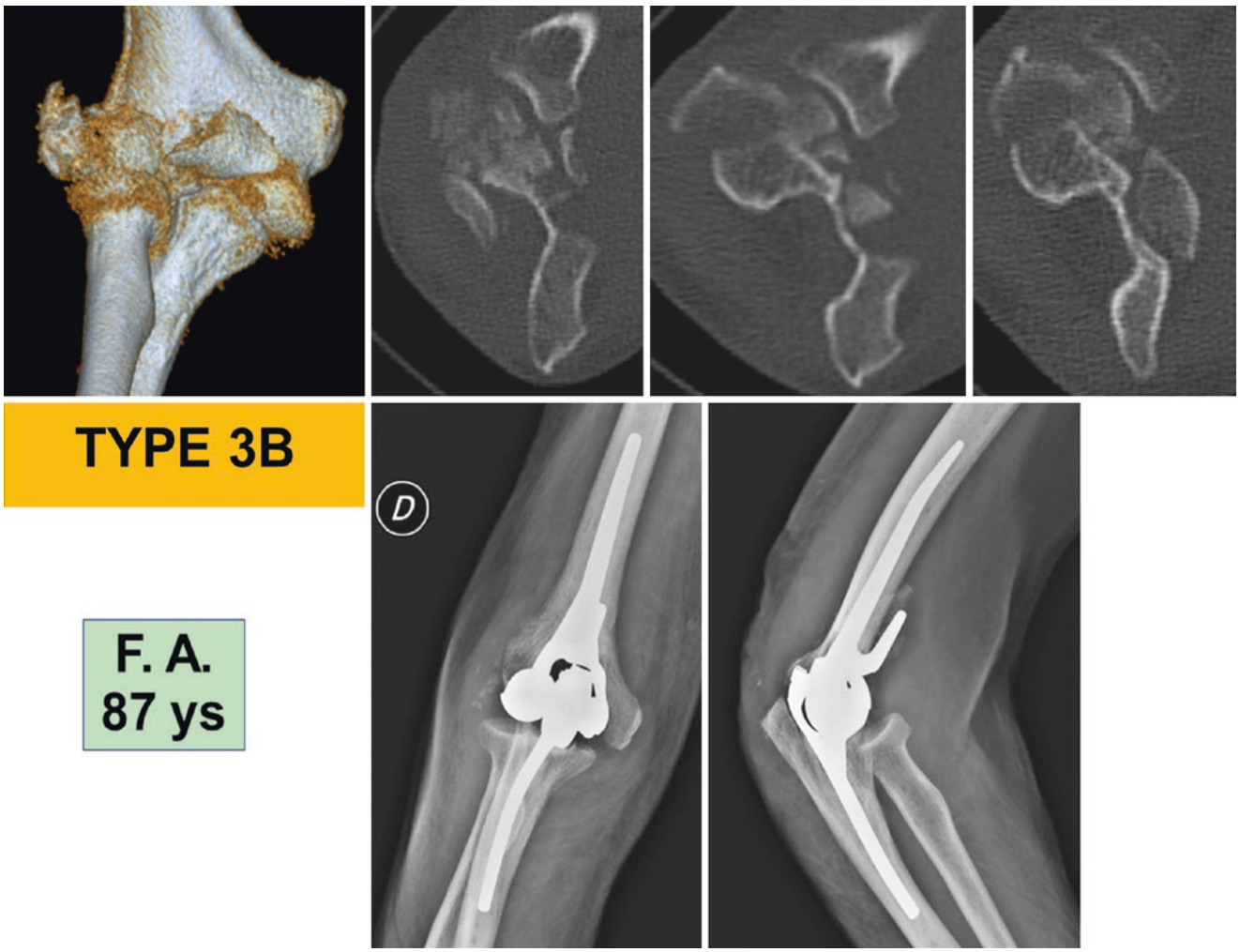


Fig. 15.3 Total elbow replacement for comminuted fracture (type 3B Dubberley classification) in an elderly and low-demand patient

fixator. The prosthetic replacement may be considered if stable internal fixation cannot be achieved in lower-demand or elderly patients (Fig. 15.3). Distal humerus hemiarthroplasty can be an appealing option in the capitellar and trochlear fractures that present integrity of columns and collateral ligaments, especially in relatively young patients (Rotini et al. 2015).

15.3.1 Surgical Technique

If an olecranon osteotomy is not the indicated approach, our preference is for a lateral skin incision that is centered over the lateral epicondyle and extended from the anterior aspect of the lateral column to approximatively 2 cm distal to the radial head.

Proximally the distal and anterior part of the lateral column is exposed, and distally the Kocher interval is exploited, preserving the LUCL. With the elbow flexed, placing a large and blunt Hohmann retractor beneath the anterior capsule and the brachialis muscle, just over the medial column, it is possible to have a good exposure of the capitellum and of the lateral part of the trochlea. If a bigger part of the anterior trochlea is involved, an extensive lateral exposure with elbow subluxation is indicated; if also the posterior trochlea and/or the medial epicondyle is involved, then olecranon osteotomy is necessary. The anterolateral approach is a possible alternative approach, but its use is until now rarely reported in the literature for the risks related to the dissection near the anterior neurovascular structures and for the difficulty related to this approach in treating the frequent associated injuries, like lateral collateral ligament injury or lateral condyle fracture. Independently of the approach used, the

articular fragments are carefully reduced and temporarily fixed with Kirschner wires placed along the fracture margin so as not to interfere with placement of the screws; in case of difficulties in reducing the fragment, the posteroinferior aspects of the distal lateral column and trochlea should be evaluated for impaction and comminution.

Definitive fixation of the capitellar and trochlear fragments is achieved with screws, if possible at least two with divergent directions.

The direction of the screws can be decided based on the type of fracture and on the surgeon preference: with out-in direction (from posterior to anterior) it is possible to use partially threaded cancellous screws or with in-out direction (from anterior to posterior) cannulated, headless, variable thread pitch compression screws (metallic or resorbable) buried beneath the articular surface.

Our preference goes to the in-out technique to obtain a stronger and more accurate fixation, preserving the posterior vascular support that is the main blood supply for the lateral column and capitellum. The specific advantages and disadvantages of *in-out* and *out-in* techniques are summarized in Table 15.2.

If the lateral column is also involved, a short precontoured buttress plate is recommended (Fig. 15.4).

In comminuted fractures, multiple pin fixation can be an alternative to elbow replacement in younger patients (Fig. 15.5).

The role of the arthroscopic technique in the management of this type of fractures likely will increase in the future. Until now only very few cases of arthroscopic fixation (ARIF) have been reported (Hardy et al. 2002; Mitani et al. 2009; Kuriyama et al. 2010). Type 1A or 2A fractures of Dubberley classification are the accepted indications for ARIF (Guerra et al. 2013).

The difficulties in the management of posterior comminution and the frequent association with lateral column fractures and with lateral collateral ligament injuries make the arthroscopic treatment still limited.

Table 15.2 Specific advantages and disadvantages of *out-in* and *in-out* screw fixation technique

Screw out-in direction
– *Advantages*
• No cartilage damage to insert the screws
• Screws easy to remove if avascular necrosis occurs
• Cheaper screws can be used
– *Disadvantages*
• Not useful in very thin fragments
• Less precision in screw insertion
• Bigger posterior soft tissue detachment
Screw in-out direction
– *Advantages*
• More precise entry point to fix the fracture
• More fixation strength in thin fragments
– *Disadvantages*
• Possible difficulties in screws removal
• A little damage is produced on the cartilage

15.3.1.1 Postoperative Treatment

After surgery the elbow is immobilized in a lightweight, removable thermoplastic orthosis, with the elbow in 90 degrees of flexion. To make the rehabilitation treatment of elbow intra-articular fractures appropriate and effective, a direct relationship among the surgeon, the physiotherapy team, and the patient is necessary. The physiatrist and therapist need to be aware of many clinical information as the type of fracture and the stability of the synthesis, the presence of associated injuries, the surgical approach, the additional surgical procedures performed (e.g., radial head fixation or lateral collateral ligament repair), and the state of the periarticular soft tissues (Fusaro et al. 2014).

Based on all these information, the rehabilitation program is established. In the majority of cases, active auto-assisted motion can be encouraged on the first postoperative days.

If there is a deficit of the LCL, the range of motion is improved with the forearm in pronation. On the contrary, in the rare cases where there is a deficit of the MCL, the flexion-extension of the elbow is performed with the forearm in supination. To make it easy to remind, we have called this method the "Fonzie's thumb rule," that is, the thumb must be put in the direction of the strongest ligament (Fig. 15.6). The protected arc of motion is progressively increased on a weekly basis. Forearm rotation is encouraged and performed with the elbow flexed beyond 90°. Radiographs are recommended after 2–3 weeks to ensure that the fracture has remained reduced.

After 3–4 weeks, the use of the thermoplastic orthosis is progressively discontinued, and a formal physiotherapy program can be started. Unrestricted range of motion begins at 4 weeks. Progressive strengthening is initiated at 8–10 weeks postoperatively.

A splinting daily program with a mobilization brace (Marinelli et al. 2010) can be used in case of stiffness after 4 weeks.

15.4 Pearls and Tricks

15.4.1 Recognizing the Specific Type of Injury

These types of fractures present a wide spectrum of injury patterns ranging from relatively simple lesions that involve only the capitellum, with good subchondral bone, to very

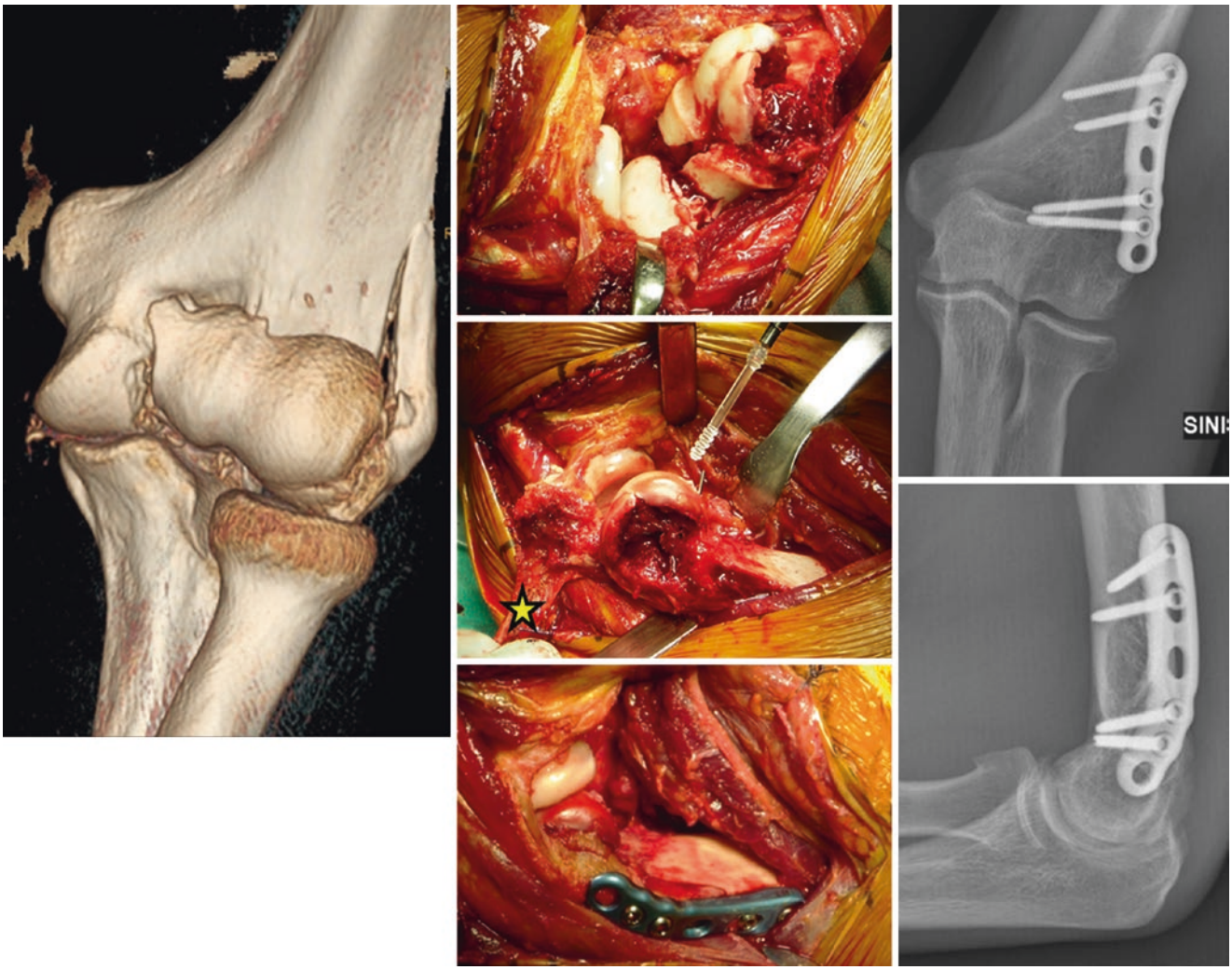


Fig. 15.4 31-year-old male patient with a type 2A Dubberley classification, capitellar-trochlear fracture, and involvement of the lateral condyle. The lateral condyle fracture (*yellow star*) has been used to subluxate the elbow in order to expose the anterior articular surface, conserving the lateral collateral ligament insertion. After reduction and fixation of the articular fragments with resorbable screws, the lateral condyle was buttressed with a short precontoured plate

complex fractures with extensive fragmentation and comminution (Fig. 15.7).

On a plain X-ray, it is easy to underestimate the true extent of the injury, like posterior comminution and trochlear involvement, and a good-quality CT scan study with two- and three-dimensional reconstructions is usually recommended for the preoperative planning.

In almost 80% of the cases, the capitellar fracture extends medially to involve *a part of the trochlea* (Ring et al. 2003; Dubberley et al. 2006; Watts et al. 2007; Guitton et al. 2009), *in up* to 40% of the cases the lateral collateral ligament is injured, and a radial head fracture is present in almost 10–30% *of the cases* (Dubberley et al. 2006; Mighell et al. 2010; Heck et al. 2012).

More complex fractures nearly always involve a fracture of the lateral epicondyle.

Understanding the fracture complexity is fundamental to decide the approach and the surgical instruments that need to be available in the operating room.

15.4.2 Choosing the Right Approach

The strategic choice of the approach is the key element for a successful treatment (Marinelli et al. 2015). Many algorithms have been recently proposed (Ring 2007; Dubberley et al. 2006; Faber 2004; Durakbasa et al. 2013; Ring 2009). Based on our experience, this is our suggested algorithm:



Fig. 15.5 53-year-old female patient with a type 3B Dubberley classification fracture. The patient was treated with transolecranon approach and fixation of the many comminuted fragments using multiple metallic K-wires. A good clinical result has been achieved at 2-year follow-up

- The fractures involving the capitellum and a little part of the trochlea (type 1 of Dubberley classification) can be treated through a Kocher approach preserving the lateral collateral ligament (Fig. 15.8a). The fixation technique can be performed with out-in direction or with in-out direction using cannulated, headless, variable thread pitch screws (Table 15.2).
- In more complex fractures with involvement of all the trochlea, with or without fragmentation (types 2 and 3 of Dubberley classification), it is necessary to use the extensile posterolateral approach described by Morrey (Fig. 15.8b). It consists in performing proximally a column procedure with the detachment of the common extensor tendon, of the lateral collateral ligament, and of the capsule; moreover the triceps is detached from the posterior humerus and, if needed, the anconeus from the ulna. After that, it is possible to subluxate the elbow with a stress maneuver in varus, flexion, and supination in order to expose the anterior articular surface of the distal humerus.
- In the same way, in case of lateral epicondyle fracture, it is possible to take advantage of this fracture for subluxing the joint, conserving the lateral collateral ligament (Fig. 15.4).
- In the fractures with involvement also of posterior trochlea and medial epicondyle, it is convenient to perform a transolecranon approach for a better exposure and an adequate fixation (Fig. 15.8c).
- In case of associated olecranon fractures, it is possible to take advantage of the fracture for the approach.

15.4.3 Trying Fixation in Every Possible Case

In these types of fractures, the percentage of clinically significant avascular necrosis is less common than expected also in comminuted cases or when the fracture reconstruction is made on the back table. So it is important in our opinion to try primarily to perform a good fragment fixation in every possible case, considering fragment removal or prosthetic replacement only in very selected cases.

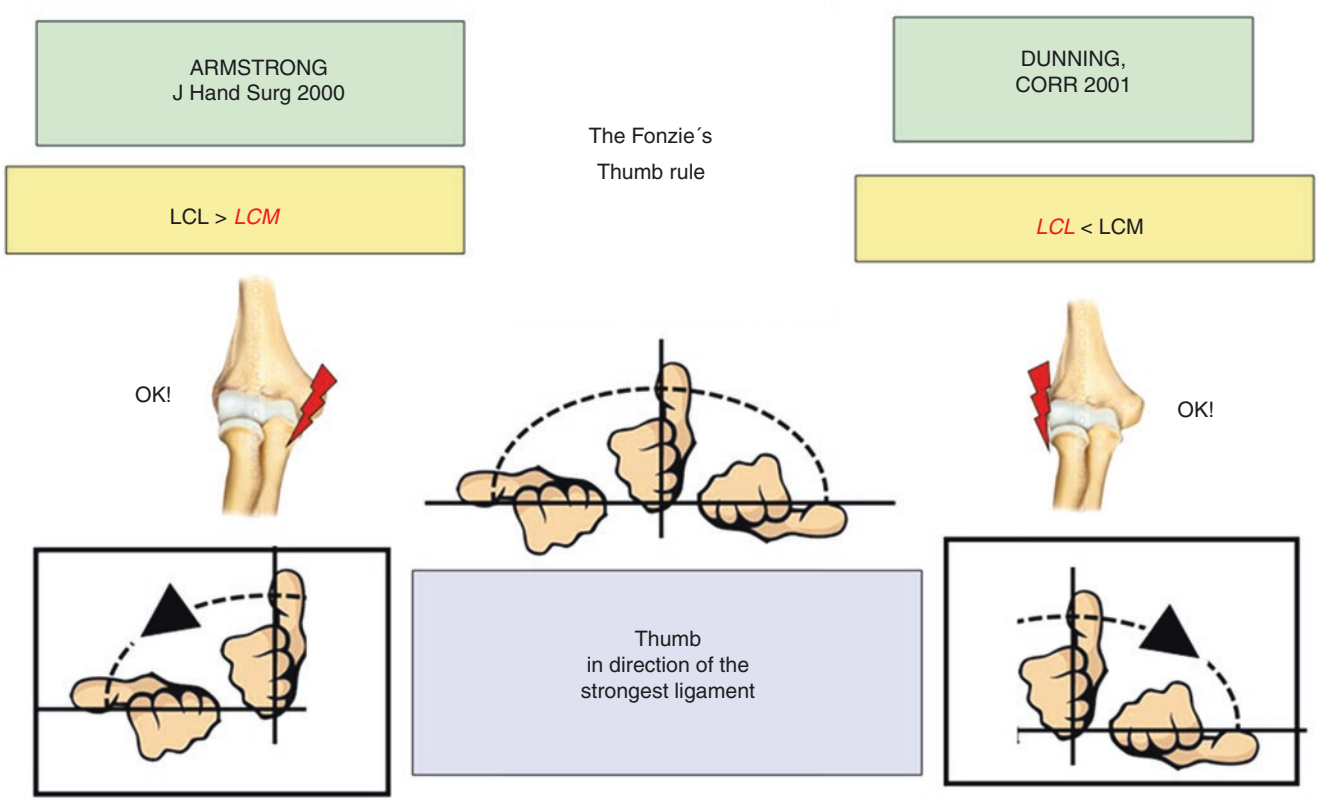


Fig. 15.6 The Fonzie's thumb rule for elbow rehabilitation in case of lateral or medial collateral ligament: the thumb must be directed in the direction of the strongest ligament. It is useful to remind the ligament-specific rehabilitation protocol proposed by Armstrong for LCM (Armstrong AD et al., J Hand Surg Am. 2000) and Dunning for LCL (Dunning CE et al., Clin Orthop Relat Res. 2001)

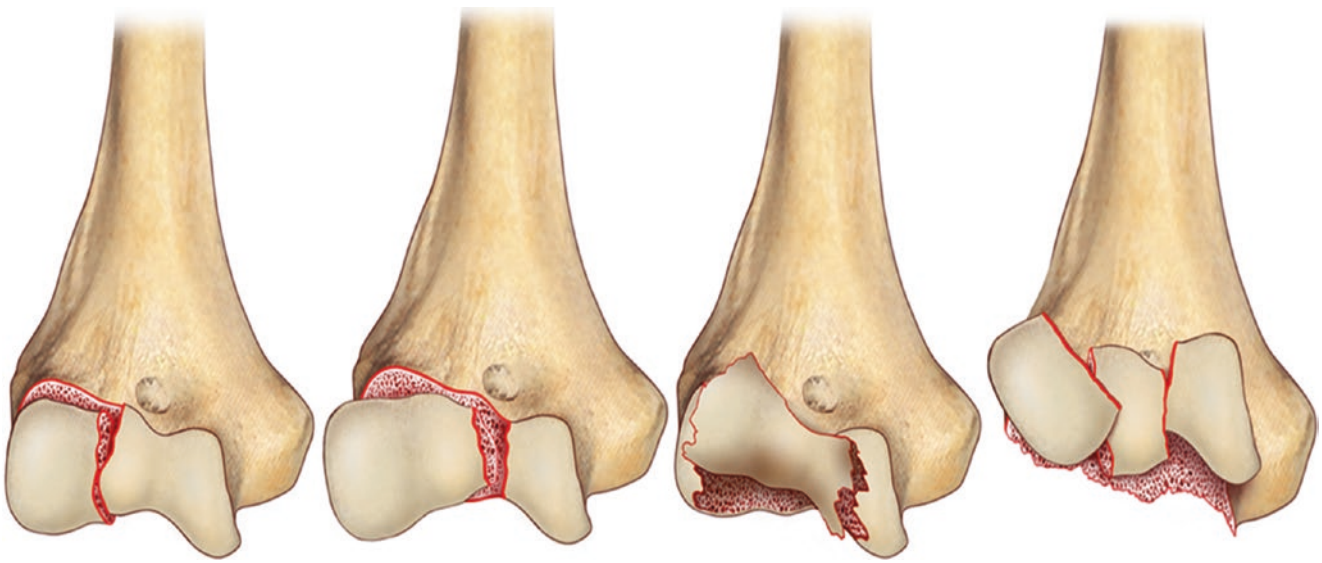


Fig. 15.7 The wide spectrum of fracture patterns of articular fracture of the distal humerus: from relatively simple lesions that interest only the capitellum, with good subchondral bone, to very complex fractures with extensive fragmentation and comminution

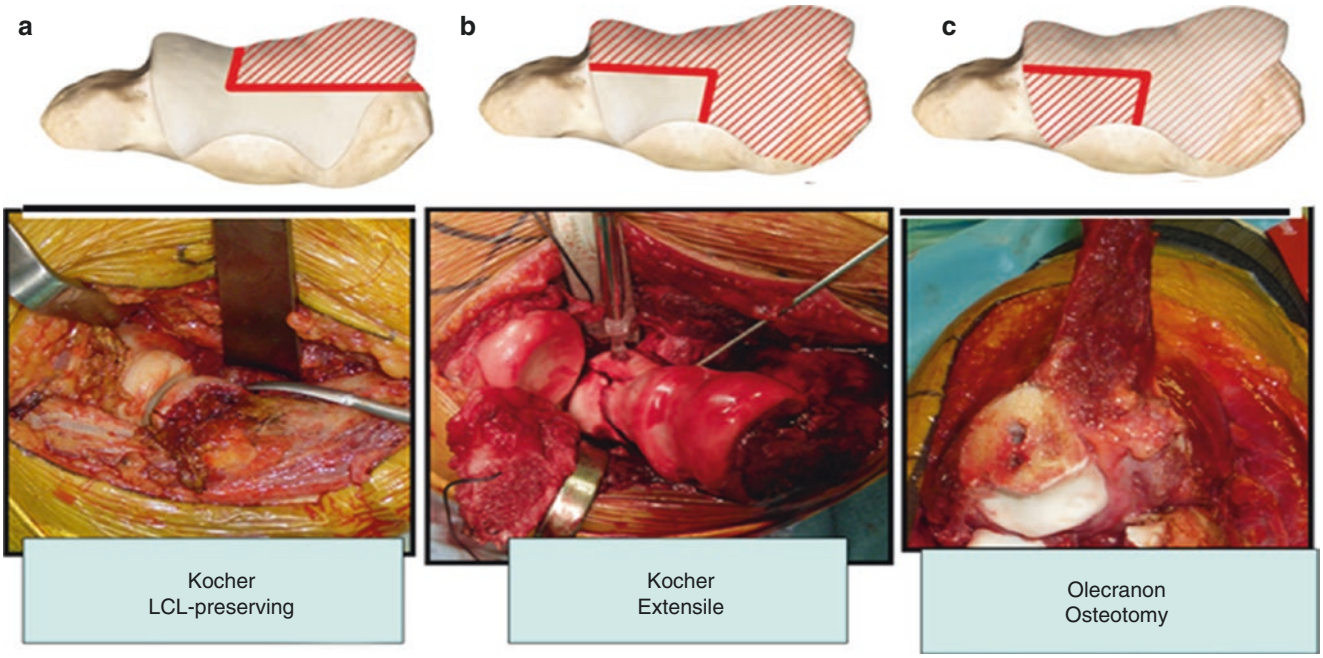


Fig. 15.8 Decision-making approach based on the fracture pattern: (**a**) type 1 fractures of Dubberley classification can be treated through a Kocher approach preserving the lateral collateral ligament. (**b**) Type 2 and type 3 fractures of Dubberley classification require an extensile posterolateral approach. (**c**) Capitellar and trochlear fractures involving also the posterior trochlea and the medial epicondyle usually need a transolecranon approach

Table 15.3 The specific advantages and disadvantages of resorbable and metallic screws

Resorbable screws
– *Advantages*
• No removal
• Minor image distortion (CT scan or MRI)
– *Disadvantages*
• More expensive (at least three times)
• Possible local inflammatory reaction
• Require precise and accurate technique
• In osteoporotic bone less compression strength
Metallic screws
– *Advantages*
• Cheaper
• More mechanical compression strength, mostly in weak bone
• Easier surgical technique
• No risk of local inflammatory reaction
– *Disadvantages*
• Possible need of removal
• Metal artifact on CT scan or MRI

15.4.4 Considering the Use of Resorbable Screws and Pins

The use of resorbable screws and pins with anterior to posterior direction can avoid a further surgery to remove the implants, like in case of avascular necrosis causing hardware protrusion.

It is important to consider that in some cases it can be difficult to remove the screws implanted during the first surgery, because they were inserted with the elbow dislocated or exploiting a transolecranon approach. In these cases the exposure to remove the hardware can be very aggressive, and the possibility to use resorbable screws is appealing. The specific advantages and disadvantages of resorbable or metallic screws are summarized in Table 15.3.

The time of resorption is depending on many variables, like materials, processing techniques, size and shape of the screws, type of bone, and the mechanical stress received. However, the companies report a mean time for resorption of 3–5 years.

15.4.5 Using Superior and Medial Border of the Capitellum as the Reliable Reference Points for Fracture Reduction

In some cases it is possible to find difficulties in anatomical reduction of the fractured fragments because of the impaction causing a plastic deformation of the posterior part of the capitellum or trochlea. Such posterior impaction is not easily detectable on plain X-rays or on the surgical field. In these cases the inferior and lateral parts of the posterior capitellum are the most deformed parts, and the inferior aspect of the capitellum should not be used as a reference for final reduction. On the contrary the superior and medial margin of the capitellar fragment are reliable reference points.

15.5 Results

The rarity of these fractures makes it extremely difficult to perform studies in a prospective or randomized manner. Therefore, until now, all the few studies reported in the literature are retrospective case series (level IV evidence).

Based on our experience and analyzing the published case series which used current surgical techniques and fixation devices, we can deduce positive results can be achieved in the majority of patients treated with ORIF (McKee et al. 1996; Ring et al. 2003; Dubberley et al. 2006; Watts et al. 2007; Guitton et al. 2009; Mighell et al. 2010; Heck et al. 2012; Ruchelsman et al. 2008; Ashwood et al. 2010) (Table 15.4). In particular in simplest cases, involving only the capitellum or a limited part of the trochlea, without posterior comminution, in every reported case series, the outcomes are usually good to excellent. On the opposite side, recognized negative prognostic factors are the extension in the trochlea, fracture fragmentation, and posterior comminution. Also in great-experience institutions, in the cases with considerable medial extension or comminution, the reported complications are relatively common (Table 15.4), and the rate of reoperation, especially for contracture release and hardware removal, is high: 10/21 Ring et al. (2003), 12/28 Dubberley et al. (2006), and 18/27 Guitton et al. (2009). Especially in complex cases, mild to moderate post-traumatic osteoarthritis may be anticipated at midterm follow-up. On the opposite, despite the size of the fragments, the displacement, the possible presence of posterior metaphyseal comminution, and the limited soft tissue attachments, avascular necrosis is rare, and when present, it usually is a little symptomatic. The postoperative rehabilitation should be based on the intraoperative assessment of the quality of the bone fixation and of the collateral ligament condition. In the majority of cases, active auto-assisted motion can be encouraged from the first postoperative days, and after 3–4 weeks, the use of the thermoplastic orthosis is progressively discontinued, and a formal physiotherapy program can be started. The Fonzie's rule is useful to memorize the ligament-specific rehabilitation protocol. We can conclude that certainly now we are more skilled to understand and to treat these lesions compared to the past years, but the rate of complications in complex cases is still high.

Table 15.4 Clinical results, complications, and subsequent surgeries after open reduction and internal fixation in capitellar and trochlear fractures

Author	Patients number	Mean FU (months)	Scores	Mean ulnohumeral arc (°)	Results	Complications	Subsequent surgery
McKee	6	22	Broberg-Morrey	126	3 excellent, 3 good	1 arthritis	1
Ring	21	41	MEPI	96	4 excellent, 12 good, 5 fair	6 release, 2 ulnar nerve treatment, 1 early loss of fixation, 1 hardware removal	10
Dubberley	28 (26 ORIF)	53	MEPI	119	17 excellent, 8 good, 1 fair	7 release and hardware removal, 6 hardware removal, 2 nonunion, 1 AVN, 1 screw back out, 4 periarticular calcifications, 9 post traumatic arthritis	12
Ruchelsman	16	25	MEPI	123	9 excellent, 6 good, 1 fair	Not reported	1
Mighell	18	26	Broberg-Morrey	128	12 excellent, 5 good, 1 fair	3 AVN, 5 arthrosis, 3 heterotopic ossifications, 1 superficial infection, 1 stiffness without reoperation	0
Rotini (unpublished data)	28	24	MEPI	117	16 excellent, 9 good, 3 fair	3 heterotopic ossifications, 4 post-traumatic arthritis, 2 ulnar nerve disease, 1 elbow instability, 2 hardware failure, 1 AVN	6
Ashwood	26	46	MEPI	120	9 excellent, 9 good, 8 fair,	2 regional sympathetic mediated pain syndrome, 2 ulnar nerve neuropathy, 4 superficial infection	6

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Arthroscopic Treatment of Elbow Fractures

16

Enrico Guerra, Alessandro Marinelli, Graziano Bettelli, Marco Cavallo, Alice Ritali, and Roberto Rotini

16.1 Introduction

Arthroscopy of the elbow is a relatively recent surgical procedure. Although the first experience described in the literature dates back to the 1980s, it is only in the last 15 years that a real and increasing interest can be seen with the inclusion of series of patients (Kelly et al. 2001) and case reports that describe the research for new indications.

Intra-articular fractures, by their definition, should be anatomically reduced with extreme accuracy besides being fixed in a stable manner. Arthroscopy has already shown its usefulness in all the joints, by improving the visual field of the joint surface with a minimally invasive surgical approach.

Besides several case reports in the literature on single fractures, Peden et al. (2010) performed the first overview on this innovative elbow arthroscopy technique.

The literature shows little scientific evidence about the various indications for arthroscopy of the elbow (Yeoh et al. 2012). These indications include fractures of the radial head, capitellum, trochlea, and coronoid.

This chapter addresses the various articular fractures of the elbow, where arthroscopy can nowadays be considered to be a real help. The most important technical aspects are summarized in the light of the literature and the authors' personal experience.

16.2 Fractures of the *Capitulum Humeri* and Trochlea (Shear Fracture)

Fractures of the *capitulum humeri* and trochlea are rare fractures that alter the joint considerably. Even when they are not the result of high-energy trauma, they produce severe stiffness and instability in the elbow, if they are not immediately recognized and treated adequately (Ring et al. 2003).

Various classifications try to group the various morphologies and determine correct treatment algorithms (Bryan and Morrey (1985), McKee et al. (1996), Ring et al. (2003), Dubberley et al. (2006)). Anatomical reduction is necessary to restore the joint anatomy and the correct tension of the external ligament compartment.

16.2.1 In the Literature

Only a few cases have been described. Feldman (1997) reported two cases of fracture with thin osteochondral fragments (type 2 fracture, Regan and Morrey). Having ascertained the absence of combined joint instability, the author decided for the simple removal of the fragments by arthroscopy using two approaches, anteromedial and anterolateral.

Hardy et al. (2002) described reduction and fixation of a Hahn-Steinthal fracture (type I, Regan and Morrey) achieved arthroscopically, by three different anterolateral approaches. The metal screw, in the subchondral bone, must be tilted from lateral to medial on the frontal plane, to avoid the radial nerve.

Mitani et al. (2009) published a new clinical case with interesting practical advice. By two simple anteromedial and anterolateral portals, he used the arthroscope together with the probe to reduce the displaced osteochondral fragment; maintaining the reduction with the probe from the anterolateral portal, he performed fixation with two metal screws in a posteroanterior direction.

The following year Kuriyama et al. (2010) went a step further by attempting arthroscopic reduction and fixation (ARIF) of two more complex cases (type IIIA Dubberley) through two portals (anterolateral and midlateral). In one of the two cases, the operation was transformed into open surgery, albeit with an incision of only a few centimeters.

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16.2.2 Surgical Technique in Our Experience

From 2000 to 2012, about 48 type I or type II shear fractures were treated in our department by open reduction and internal fixation in 43 cases and by miniopen technique in 5 cases. Our experience with arthroscopic treatment started in 2004 with three type III fractures in which we performed fragment removal. In the last 2 years, our indications were widened to include strictly selected type I and type II fractures (5 cases).

All the patients underwent preoperative CT of the elbow that is essential to define the fracture morphology and to find medial fracture lines directed toward the trochlea or impacted fractures with osteochondral fragments deformity (so-called elbow Hill-Sachs lesions) which can make the reduction more difficult.

In open surgery, the Kocher approach extended proximally (Extensile Kocher approach) with posterolateral subluxation maneuvers, enabling easy control over both the anterior articular compartment (with access to the medial trochlea) and the posterior one (to treat impacted lesions).

The capitellum and trochlea fractures that come to our attention are apparently simple injuries. The CT nearly always shows more medial fracture lines (toward the trochlea) or impact lesions with deformation of the osteochondral fragments (elbow Hill-Sachs lesions) that make reduction difficult. In arthroscopic surgery, the fracture must be well visualized in the anterior compartment and the posterolateral gutter (Fig. 16.1). Therefore, if arthroscopic treatment is selected, it is not sufficient in our opinion to perform only the anterior or posterolateral portals, but it is necessary to move the arthroscope several times, before performing fixation, which is a very complex procedure.

It is common to find an intraoperative lesion of the external collateral ligament complex, which, in open surgery, can be repaired.

Another aspect to take into consideration is the direction of the fixation. We strongly advocate anterograde fixation, with screws and pins made of polylactic acid. In this direction, compression fixation can be performed by sinking the screws under the cartilage plane, perpendicularly to the fracture lines. If the ARIF technique is chosen, screws that enter posteriorly are needed in order to avoid risks to the radial nerve. Therefore, the screws are made of metal, and making thinner fractures stable (type 2) will be difficult.

These reasons suggest restricting arthroscopic treatment of capitellum and trochlea fractures to rare cases that fulfill the following criteria:

- Type I fractures (Hahn-Steinthal) without posterior depression
- Type III fractures
- Absence of combined ligament lesions

For the recommended surgical technique, the patient is placed in a lateral position. Insufflate sterile saline solution repeatedly to drain the hematoma before starting surgery (useful tip in the arthroscopic treatment of all intraarticular fractures). By using three approaches, anteromedial, anterolateral, and proximal anterolateral arthroscopic, appropriate joint shaving and lesion planning can be performed, by keeping the arthroscope in the medial portals and working through

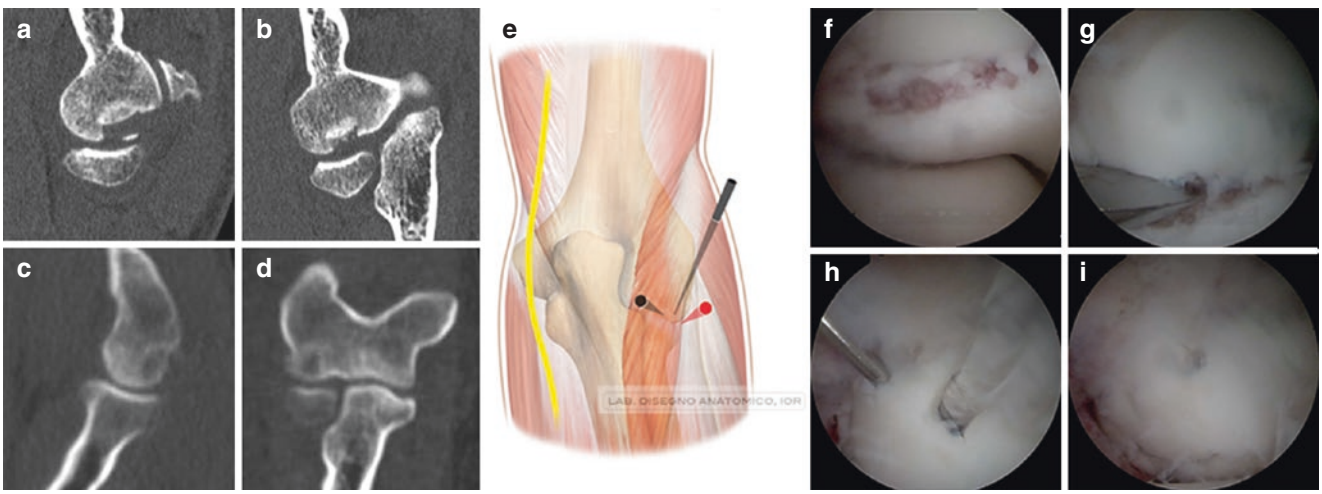


Fig. 16.1 Impacted capitellum fracture. Thirty-six-year-old patient, right elbow. CT scan image of a rare impacted fracture of the posterior face of the capitellum before (**a**, **b**) and after (**c**, **d**) reduction and fixation. Drawing (**e**) of the arthroscopic portals used to perform ARIF of the fracture. Examination of the anterior joint compartment allowed to remove the intra-articular fractured tip of the coronoid. In order to visualize the fracture, it was necessary to reach the posterolateral gutter placing the scope in the posterolateral portal (**f**). Once the fracture has been reduced by a probe through the midlateral portal (**g**), fixation has been performed by a temporary percutaneous K-wire (**h**) and by a resorbable pin (**h**, **i**) (RSB implant, Hit Medica, Lima Corporate)

the two lateral portals. Some authors (Hsu and Gould 2009) recommend placing the elbow in extension to facilitate reduction. In our opinion, extension reduces the space to work, so we prefer to keep flexion at 90° and operate with the two lateral approaches. After performing temporary reduction and fixation, the fracture must be explored posterolaterally. We also recommended exploring the posterior compartment to drain the hematoma and check for any posterior loose bodies (posterolateral and posterocentral arthroscopic approaches). By the posterolateral portals, it will be thus possible to go down posterolaterally to the posterior humero-radial joint (using the palpator and shaver through the midlateral approach). At this point, by bringing the arthroscope back anteromedially under image intensifier guidance, percutaneous fixation can be performed with cannulated screws, in a posteroanterior direction (enlarging the midlateral approach).

In our five cases, we preferred to end the operation in open surgery, with a small incision that joins the anteromedial portal to the midlateral one (ideally following the incision by the Kocher approach). This miniopen surgery enabled us to perform fixation with resorbable screws and pins, in an anteroposterior direction, without putting the radial nerve at risk.

Treatment was completely arthroscopic with fragment removal in three type III cases. Also in these cases, we deem mandatory to explore by the arthroscope all the joint compartments, after having accurately examined the fracture comminution by CT scan, in order to reduce the risk of leaving debris.

The last case, apart from the presented series, is a rare impacted fracture of the capitellum combined with a coronoid tip fracture (Fig. 16.1). By arthroscopy it was possible to remove the coronoid fragment (working in the anterior compartment), to raise the impacted osteochondral fragment and fix it with resorbable pins (working in the posterolateral gutter). In this case arthroscopy displayed all of its efficacy, reducing surgical aggressiveness at a minimum.

At the end of fixation or debridement, articular stability is evaluated (possible also arthroscopically (Hsu and Gould 2009)). Faced with doubt about the stability, we recommend exploring, and possibly repairing, the lateral collateral ligament.

16.3 Coronoid Fractures

The coronoid plays a key role in elbow joint stability. Fractures were classified into three types according to their size by Regan and Morrey (1992), and only recently new more complex classifications have been devised (Regan and Morrey 1992; O'Driscoll et al. 2003) to include possible morphologies of the fragments connected to the type of injury that can produce them.

Larger fractures are caused by a direct posterior injury, whereas a posterolateral or posteromedial distortion mechanism has been identified for fractures of the apex and medial surface, respectively (sublime tubercle insertion site of the anterior bundle of the medial collateral ligament) (O'Driscoll et al. 2003).

Reduction and fixation of coronoid fractures are necessary to restore the anterior and medial elbow stability that was lost with the injury.

When combined with fractures of the radial head, which require prosthetic replacement, after radial head excision, the coronoid fracture can be reached through Kocher's lateral approach. Conversely, when the fracture is isolated, reaching and exposing the coronoid require wide approaches (anterior, anteromedial or medial), which are aggressive and not simple to perform (Pollock et al. 2009).

16.3.1 In the Literature

There are only two articles in the literature.

Liu et al. (1996) showed two cases of coronoid tip fracture, which after conservative treatment produced pain and joint stiffness. Arthroscopic removal of the fracture fragment is decisive.

But the first real experience was described by Adams et al. (2007). Two of the seven fractures described had fragments that were too small to be fixed. In four cases, arthroscopically assisted fixation (ARIF) was performed, whereas in one case open surgery was needed to perform a stronger fixation, by dedicated plate. In three of the seven cases, reconstruction of the lateral collateral ligament (LUCL) was needed.

16.3.2 Surgical Technique in Our Experience

As for capitellum fractures, coronoid fractures are very rarely isolated. Mostly, they are combined with radial head or olecranon fractures. In these cases, open surgery, necessary to treat combined fractures, cannot be replaced by arthroscopic treatment of the coronoid.

Conversely, isolated fractures of the coronoid can be treated arthroscopically. From January 2000 to July 2012, five of the eight isolated coronoid fractures treated by the authors were treated arthroscopically. Two cases were treated with reduction and fixation with wires alone, two with cannulated screws as well as K-wires, and one case with osteosuture combined with K-wires.

With the patient in a lateral position and after having washed repeatedly with needle and saline solution, the anterior arthroscopic portals are made (anteromedial, anterolateral, and anteromedial or lateroproximal). Having removed

the hematoma, the arthroscope is inserted into the anterolateral portal to assess the fracture well. With a motorized instrument and thermal ablator, the surfaces of the fragments are exposed. The retractor in the proximal anterior portal (medial or lateral) is fundamental in this phase to keep the joint space open, thus permitting working with a lower inflow pressure. The joint capsule is constantly lacerated and retracted, together with the fragment/s of the fracture. A high pressure of infusion will lead to an early extra-articular swelling, making surgery gradually more difficult and dangerous.

Through the "combined effect" of the retractor (from the proximal portal) and the probe (from the anteromedial portal), the larger articular fragments are put back in place, thus maintaining the capsular insertion, whereas the smaller ones can be removed. At this point it is useful to expose the dorsal surface of the ulna with a small incision, so that the skin and the subcutaneous tissue do not interfere with the instruments required for the fixation.

According to the size of the fragments, two different fixation techniques can be used:

- Cannulated screws and/or K-wires
- Osteosuture

Cannulated screws and/or K-wires (Fig. 16.2): After redislocating the intra-articular fracture with the lever from the proximal portal, K-wires are drilled from the posterior cortex of the ulna, keeping the arthroscope in the anterolateral portal and checking its exit from the base of the fractured coronoid (Fig. 16.2h). This action is made safer and repeatable by the use of an aiming device for cruciate ligament surgery; a small-sized tip device must be used, because it has to enter through the anteromedial portal, and a bulky tip might impinge in the brachial muscle. The intraoperative radiographic checking is useful to evaluate the direction of the wires, especially if the freehand technique is chosen.

Having placed the first K-wire, the others are placed (at least two to achieve rotational stability of the fixation).

After slightly retracting the wires, until the tip goes into the medullary bone, the fracture is reduced with the lever by the proximal portal and with an arthroscopic grasper by the anteromedial portal.

While maintaining reduction, the wires are pushed forward again, checking that they come out anteriorly to the fragments.

When the size of the fragment allows, a cannulated screw, 3.5 mm in diameter, can be placed on one of the K-wires. It is cautious to hold the tip of the intra-articular K-wire firm with

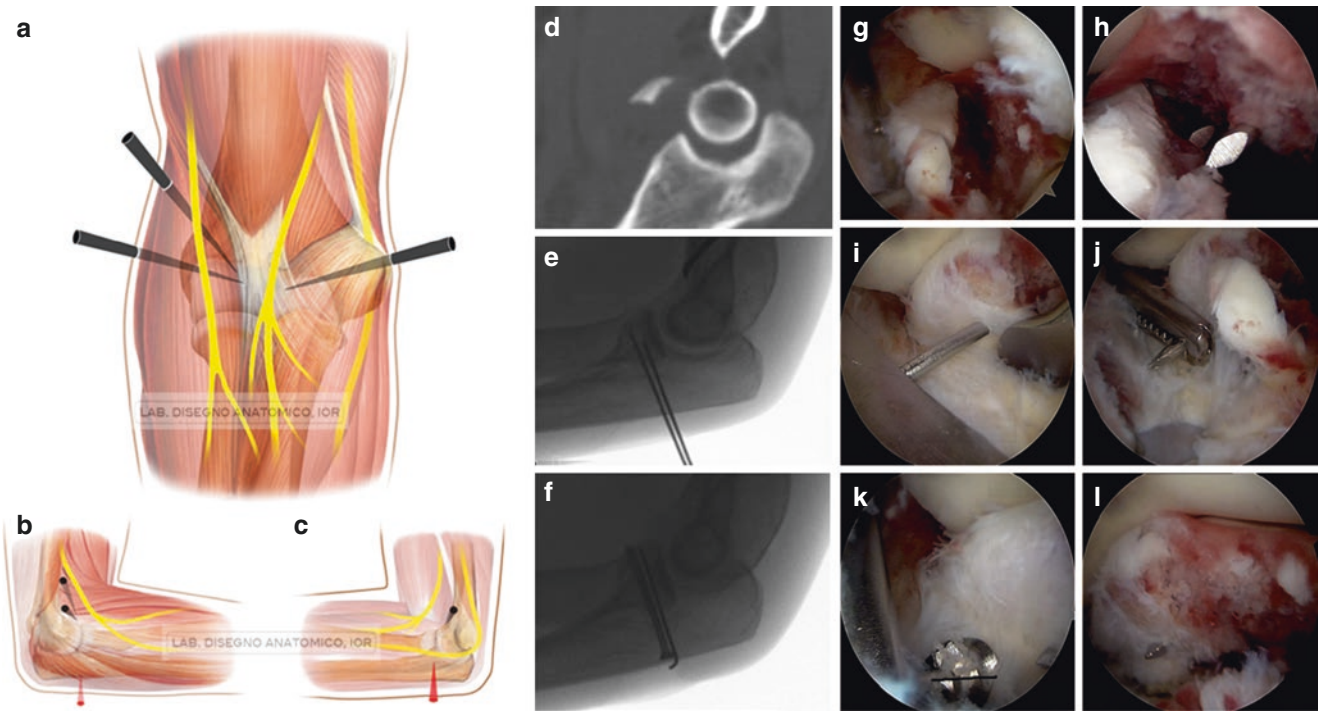


Fig. 16.2 Coronoid fracture. ARIF of a coronoid fracture (**a**, **b**, **c**) drawing of the anteromedial, anterolateral, and proximal anterolateral arthroscopic portals. In *red* the path of the percutaneous fixation (a small skin incision is advised to avoid possible K-wire impingement); (**d**) CT scan of the fracture is routinely performed to study the fracture morphology and to plan the surgical steps; (**e**, **f**) intraoperative X-ray checking of the temporary fixation by K-wires and of the definitive one by K-wire and cannulated screw. (**g–l**) Intraoperative images: the fracture is approached by the scope in the anterolateral portal, the retractor in the proximal anterolateral portal, and the shaver in the anteromedial one (**g**); at least two k-wires are placed out-in under the fracture fragments (**h**); while the fracture reduction is held, the wires are advanced behind the fragment (**i**) while protecting their tips (**i** and **j**) to prevent damage to the vascular and nervous structures. If the fragment size is adequate, fixation can be performed exploiting the wires by one or more cannulated screws (**j**, **k**, **l**)

a Kocher, while inserting the cannulated drill and the screw, to prevent the wire from being pushed anteriorly, crossing dangerously the anterior brachial muscle (Fig. 16.2j, k, 1).

Osteosuture: this is chosen when the fragments are too small and numerous to be fixed. This fixation will not be as stable as the previous one, but it enables the correct tension of the anteromedial joint capsule to be maintained while scarring takes place. Often this technique also enables small bone fragments to consolidate.

To contain the joint capsule with suture thread, the suture passer commonly used for suturing rotator cuff lesions is extremely useful. The work portal is always anteromedial, whereas the arthroscope one remains anterolateral. Once again the retractor through the accessory proximal portal plays a fundamental role.

The vector suture is replaced by a reinforced double-zero suture (Orthocord Depuy Mitek or Hi-Fi Conmed Linvatec or Fiberwire Arthrex or others).

Having placed the suture thread through the joint capsule (immediately behind the fragments of the coronoid tip), the first out-in hole is made at the base of the coronoid with a K-wire 1.4 mm in diameter. Having removed the thread, a spinal needle (18 GA 3.50 IN/1.2 mm × 90 mm spinal needle) is inserted by which a vector thread (single filament 1 mm in diameter), having been recovered from the anteromedial portal, will take the first head of the osteosuture through the ulna, posteriorly. By inserting the second head using the same technique, the osteosuture can be closed on the posterior cortex, guiding the fracture fragments with the probe (Fig. 16.3).

Regardless of the ARIF technique chosen, the fixation must be stable upon palpation and flexion-extension tests of the elbow, to reduce the period of postoperative immobilization to a minimum. Therefore, in our cases, we always supplemented screw fixation or osteosuture by K-wiring.

16.4 Radial Head Fractures

Radial head fractures, extremely common, are classified into four types by Mason and Johnston and divided further into simple and complex, according to possible combined lesions (Adams et al. 2007). The option of conservative or surgical treatment depends on the number of fragments, their displacement, whether the fracture involves the olecranon and/or coronoid and if there are ligament lesions. When surgery is the choice, the surgeon has to decide among radial head excision, reduction and fixation of the fracture, or prosthetic replacement. It has been shown that ORIF or the prosthetic replacement of the radial head enables a better recovery of

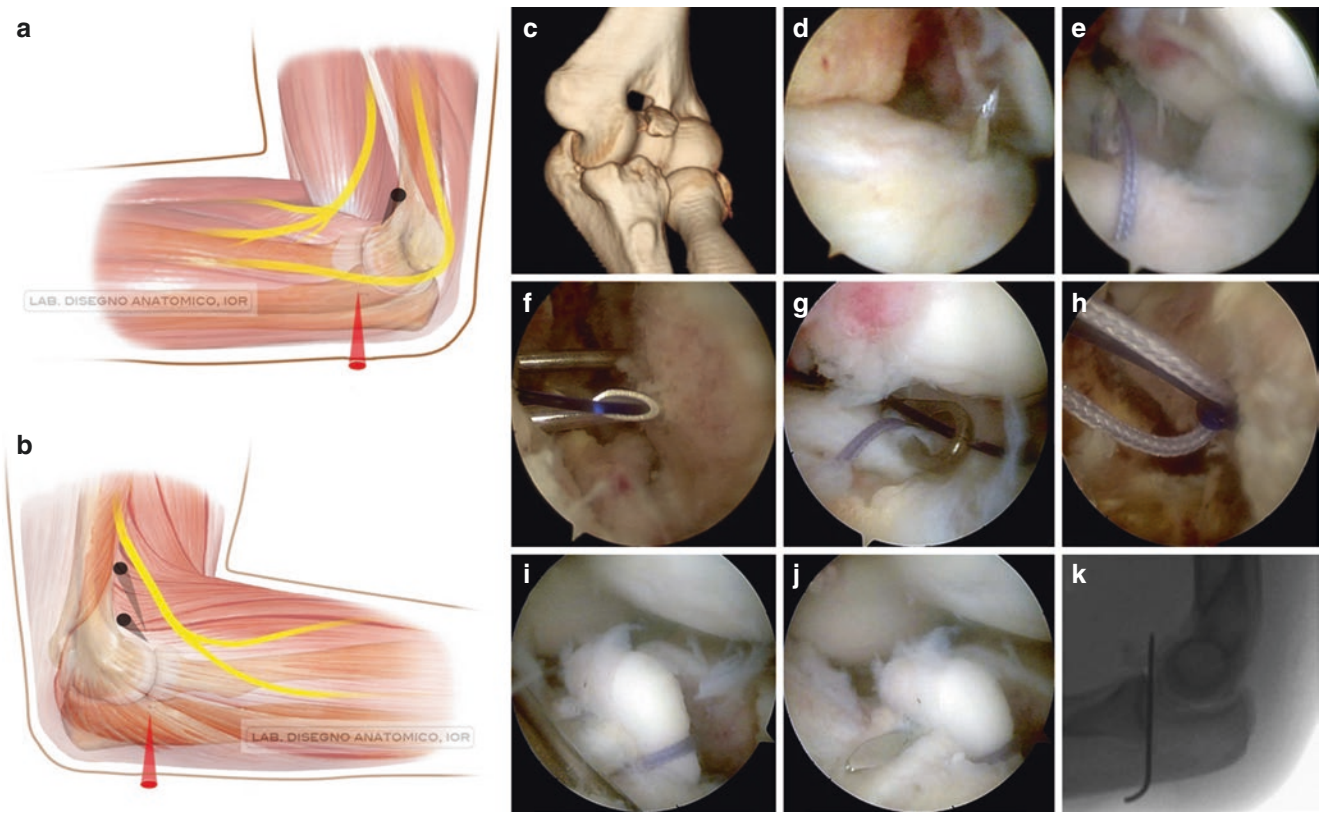


Fig. 16.3 Osteosuture of a coronoid fracture. The portals to perform osteosuture are the same as for K-wires or screw fixation (**a**, **b**). Preoperative CT scan (**c**) shows a displaced fracture, suggesting joint derangement. By placing the scope in the anterolateral portal, it is possible to arthroscopically perform an osteosuture (**d**–**i**) as described in the text, possibly reinforced by K-wires (**j** and **k**)

articular stability (van Riet et al. 2009) and therefore will certainly be the best choice when there is a combined lesion of the medial collateral ligament. Conversely, an isolated fracture of the radial head can be treated by the simple excision of the fragments (if they interfere with the passive joint range) or by full radial head excision (if more than 50% of the surface is involved).

16.4.1 In the Literature

The first arthroscopic treatment was described by Pike et al. (2009) for a fracture of the surgical neck of the proximal radius of a child, which was reduced by a manual maneuver and fixed by percutaneous wiring.

Rolla et al. (2006) published a short series of six fractures of the radial head (II, III, and IV types according to Mason) reduced and fixed with a percutaneous screw. The author used his own surgical technique and recommended reducing the fracture by working in the anterior compartment and moving in the posterolateral gutter for arthroscopic fixation.

Fourteen cases were collected by Michels et al. (2007) the following year, all Mason type II with a mean follow-up of 5.6 years and results ranging from good to excellent, matching those of open surgery. For this series the author managed ARIF by the use of only two portals (anterolateral and posterolateral) besides a small incision to insert the screws.

16.4.2 Surgical Technique in Our Experience

In our center arthroscopic treatment of isolated fractures of the radial head began in 2007. Until now 21 cases have been treated arthroscopically (seven ARIF, eight partial removals of the fragments, three radial head excisions, and three simple reductions, without fixation).

16.4.2.1 Arthroscopic Reduction Internal Fixation (ARIF) for Mason type II fractures

The first stage consists of removing the intra-articular hematoma and visualizing the fracture in the anterior compartment. We perform three approaches routinely: anteromedial (for the arthroscope), anterolateral (for the tools), and proximal anterolateral (for the retractor). The fracture is reduced by using alternately the probe from the anterolateral portal and proximal anterolateral, by pronosupination movements. Having achieved reduction, the fragments must be stabilized with K-wires, after choosing the position in pronosupination to hold for fixation.

The working position to perform screw fixation may vary. In our experience we divided the fractures according to the position of the fracture fragment/s in relation to the safe zone (part of the radial head that does not come in contact with the small sigmoid notch). Dividing the radial head ideally into two halves in neutral pronosupination, we have the lateral half (which contains the safe zone) and the medial one (Fig. 16.4).

Fractures of the lateral half can be fixed by holding the position used for reduction, by placing the forearm in pronation. The retractor and the probe hold reduction and keep the workspace open. An accessory lateral portal is directed at the radial head, and a small 5 mm cannula is placed in the joint. The cannula is important to protect the soft tissues from the rotating tools (K-wire, drill, screwdriver) as well as to prevent the thin K-wire, used to insert the screw, from bending or breaking. The K-wire is inserted through the cannula. If the fracture appears to be stable, the fixation procedure is performed (measurement, drilling, screw); otherwise other percutaneous K-wires should be placed (outside the cannula) to hold the fragment still while the drill produces the hole for the screw (Fig. 16.5).

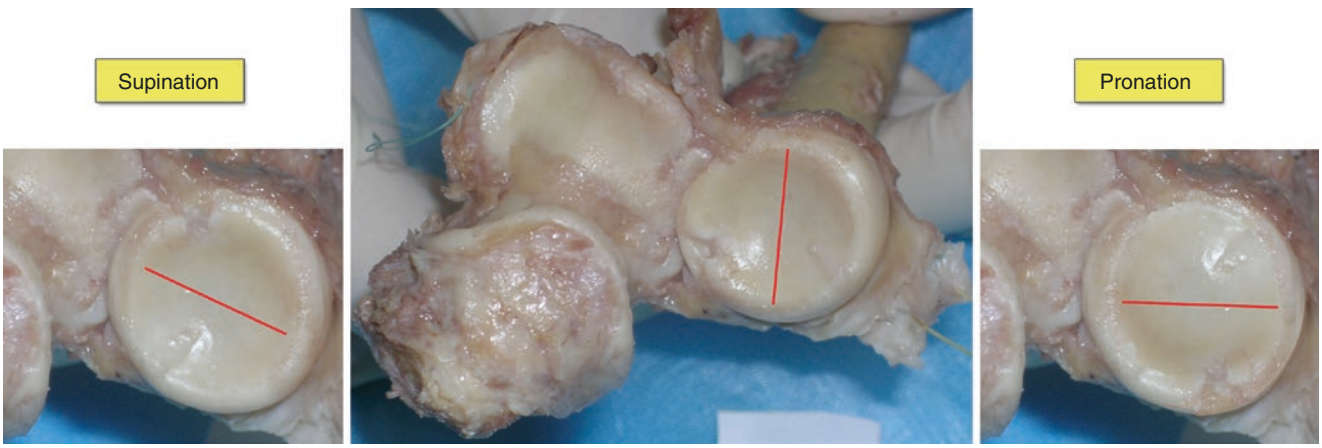


Fig. 16.4 Cadaver specimen. Radial head in full supination, in neutral position, and in full pronation. Fractures involving the side of the radial head opposite to the safe zone are more difficult to fix through the direct lateral portal

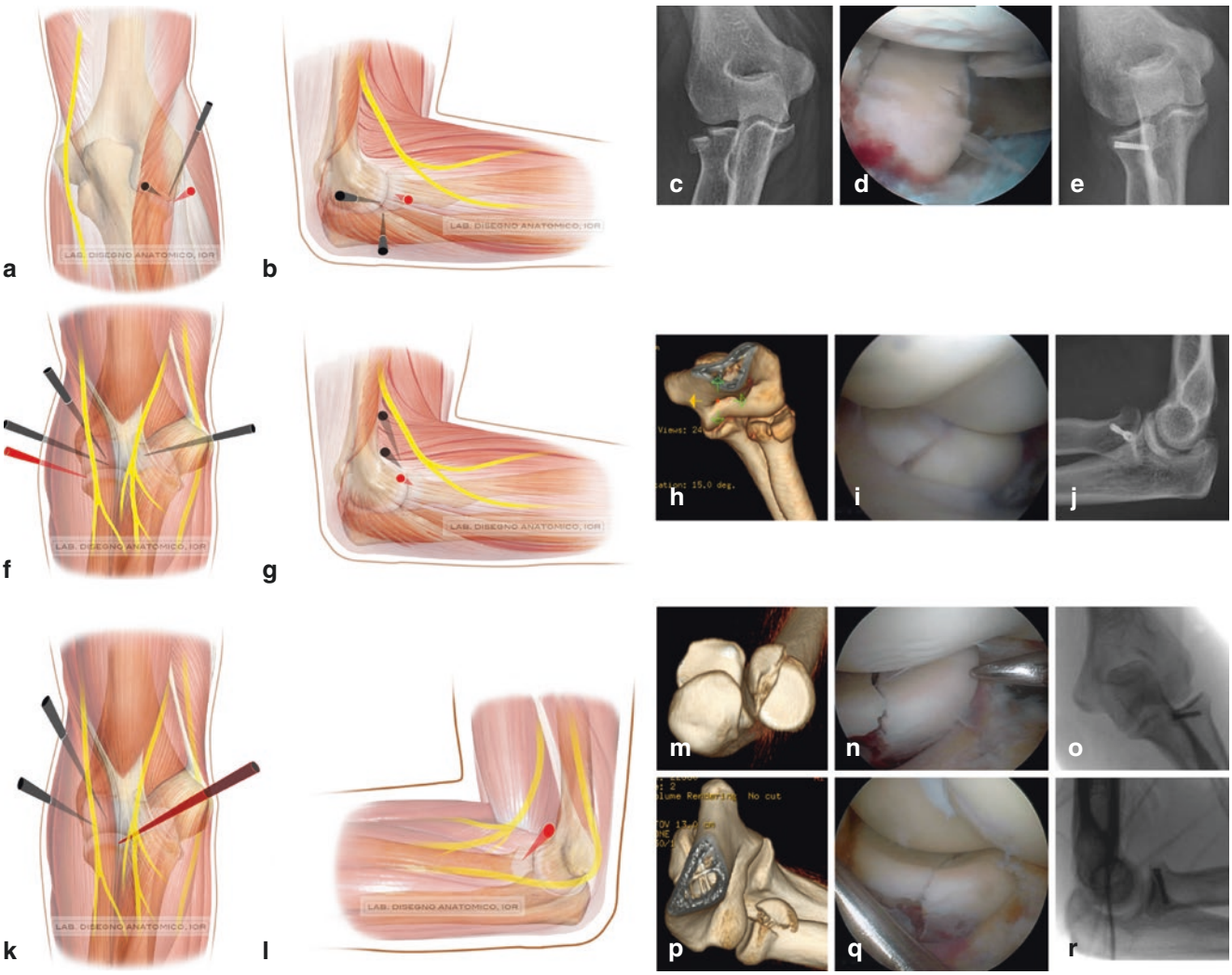


Fig. 16.5 Different fixation modes for radial head fractures. In the posterolateral gutter (**a**–**e**) and in the anterior compartment (**f**–**j**) for radial head fractures involving the lateral half, fixation will take place through a direct accessory portal (in *red*); in the anterior compartment (**k**–**r**) for fractures of the medial side of the radial head, fixation will be done through the anteromedial portal (in *red*)

Fractures of the lateral half can also be fixed by working in the (Dawson and Inostroza 2004) posterolateral gutter, by opening the posterolateral and midlateral portals to place alternately the arthroscope and the work tools. The forearm will have to be progressively placed in supination, until the fracture can be visualized. The procedure for the fixation is the same as that seen in the previous position (Fig. 16.5).

Conversely, when the fracture involves the medial half of the radial head (Fig. 16.5), pronosupination cannot put the fragment to be fixed in the correct place. In this case arthroscopic fixation can be performed by the anteromedial portal by placing the arthroscope in the anterolateral one. The work cannula is even more important to protect the soft tissues.

The ARIF described is certainly more difficult than fixation in open surgery, but offers the numerous advantages of arthroscopy. For example, in four of the seven cases treated surgically, we found small loose osteochondral fragments not visible by preoperative CT that certainly would not be found in open surgery.

However, choosing the length of the screws is more difficult because it is not easy to perform an intraoperative radiographic check with the tools in place; generally, the screws range from 14 to 18 mm long, and in case of doubt, it is better to choose a shorter screw and check at the end of fixation, without risking a loss of reduction or bending the K-wires in an attempt to get a satisfactory radiographic view.

The instruments should be chosen carefully so that the drill and the screwdriver of the 2.5 mm diameter screws are not too short, especially when fixation is performed by the anteromedial portal. If these tools are not available, the arthroscopic cannula can be cut on the serving table, before inserting it inside the joint.

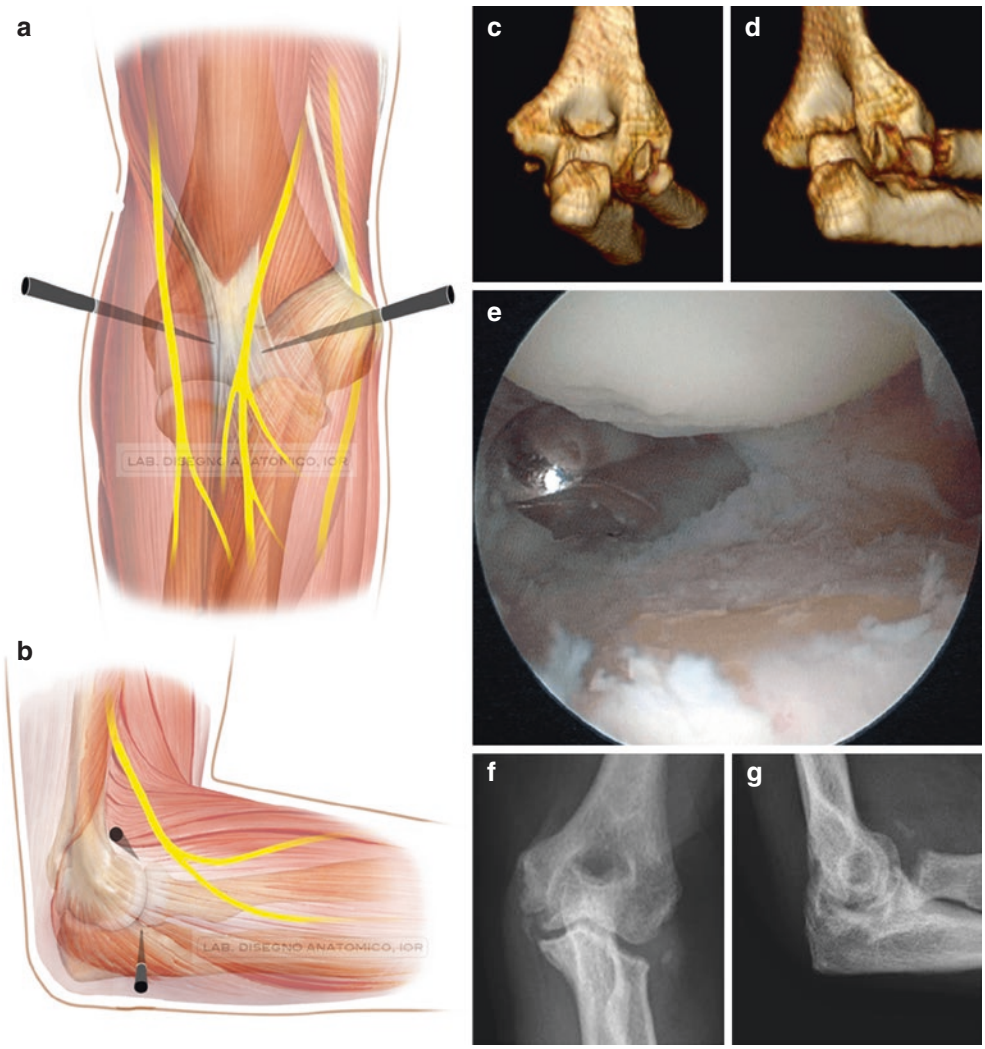


Fig. 16.6 Radial head removal of a comminuted radial head fracture in an elderly woman, performed arthroscopically through anteromedial, anterolateral and midlateral portals (**a**, **b**, **e**). Preoperative TC scan (**c**, **d**)and Radiograph of the radial head excision (**f**, **g**)

16.4.2.2 Simple Arthroscopic Reduction

In three cases of Mason fracture type II, after debriding the fracture, reduction was easy. The reduced fragment on the remaining intact part of the radial head was firmly kept in place by the annular ligament, which the arthroscopic technique leaves intact.

After several stability tests, we decided to avoid further surgical steps; all cases had a favorable outcome and full, swift recovery.

16.4.2.3 Arthroscopic Fragment Removal

In fractures with more comminution, when more than 50% of the radial head is still in site, fixation is not reliable and prosthetic replacement can be excessive.

In these cases, arthroscopic exploration enables removal of the fragments and ample joint debridement, without invalidating articular stability with the surgical approach. It is performed in the anterior compartment (by anteromedial, anterolateral, and proximal anterolateral approaches) or in the posterolateral gutter (by the posterolateral and midlateral approaches).

Arthroscopy can also be used to assess the articular stability of the ulno-humeral joint (Hsu and Gould 2009), which is important in decision-making about radial head prosthesis

16.4.2.4 Arthroscopic Radial Head Removal

When the comminution does not enable fixation, the elbow is stable, and the patient is not so young, resection of the radial head is indicated, which can be performed by arthroscopy.

After removing the fragments in the anterior compartment, resection of the radial head is precise and easy by inserting the burr through the midlateral portal while the arthroscope is still in the anteromedial portal. The radial head is cut at the level of the superior margin of the intact annular ligament. Shortening the proximal radius as little as possible without impairing the annular ligament helps to hold the tension of the lateral collateral compartment (Fig. 16.6).

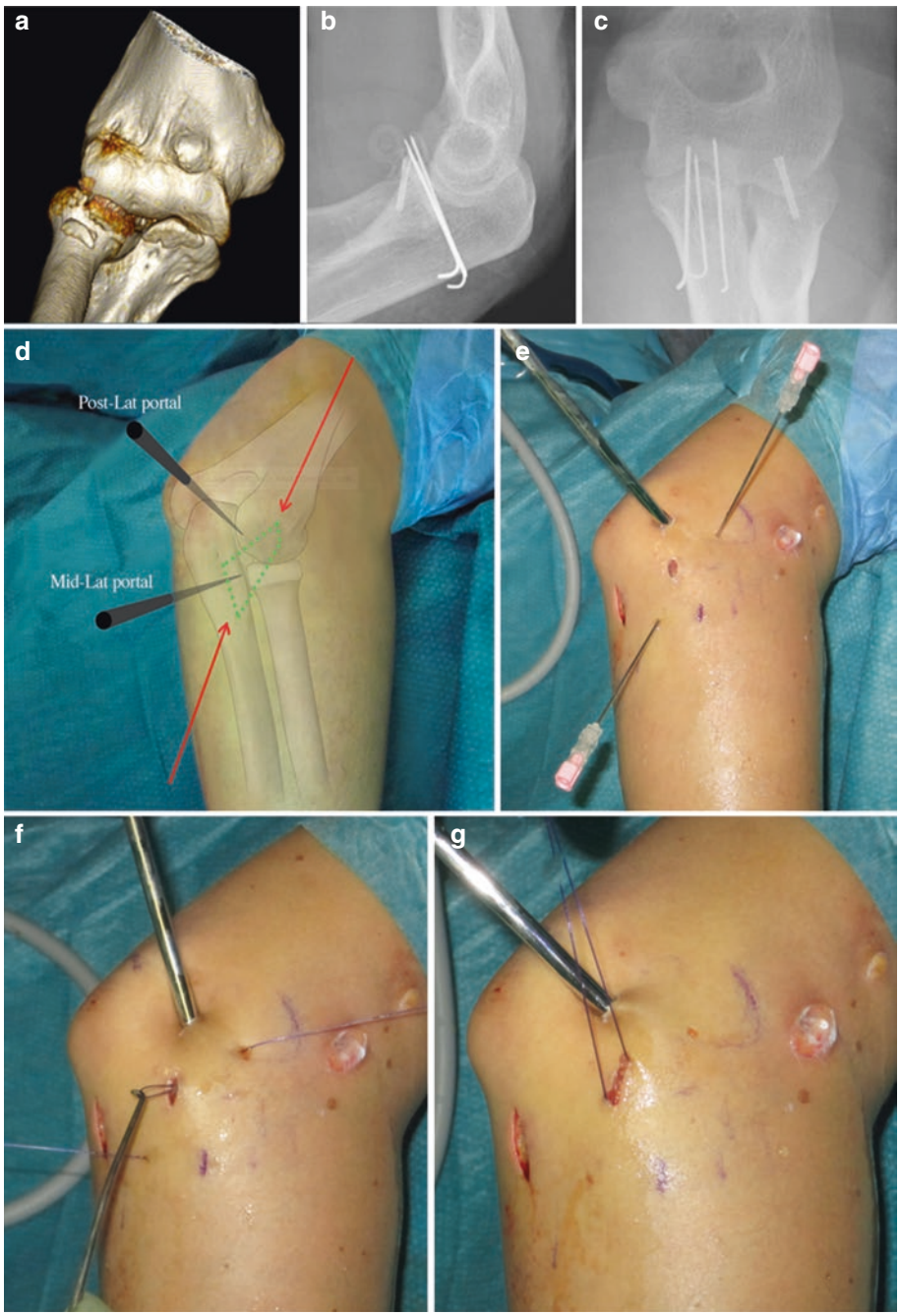


Fig. 16.7 Postero lateral plication after surgical ARIF of radial head and coronoid in Terrible triad: CT scan images (**a**) and Intraoperative X rays (**b**, **c**) of the radial head and coronoid fracture. The scope is in throught the posterolateral portal while the mid lateral portal is needed to retrive the sutures. These sutures are passed percutaneusly by two spinial needle inserted in the diresction of the fibers of the Lateral Ulnar Collateral Ligament (*green area* in **d**) as shown (**d**-**g**)

16.5 Combined Radial Head and Coronoid Fractures

We treated arthroscopically seven cases of elbow dislocation and combined radial head and coronoid fracture (terrible triad). All cases where really selectet with a fractures pattern that could be an indication of ARIF. By arthroscopy we followed carefully the path of the radial head fracture,(removing in three cases or reducing and fixing the fragments in four cases), and performed an ARIF of the coronoid (by k Wires and screws as whe have described. At the end of the synthesis the elbow wasn't deemed stable in 5 cases by dynamic tests. We proceed a posterolateral Arthroscopic assisted capsular plication (Fig.16.7). All five elbows resulted stable after the plication and were not necessary the open ligament repair. Figure.16.7 Postero lateral plication after surgical ARIF of radial head and coronoid in Terrible triad: CT scan images (**a**) and Intraoperative X rays (**b**, **c**) of the radial head and coronoid fracture. The scope is in throught the posterolateral portal while the mid lateral portal is needed to retrive the sutures. These sutures are passed percutaneusly by two spinial needle inserted in the diresction of the fibers of the Lateral Ulnar Collateral Ligament (*green area* in **d**) as shown (**d**–**g**).

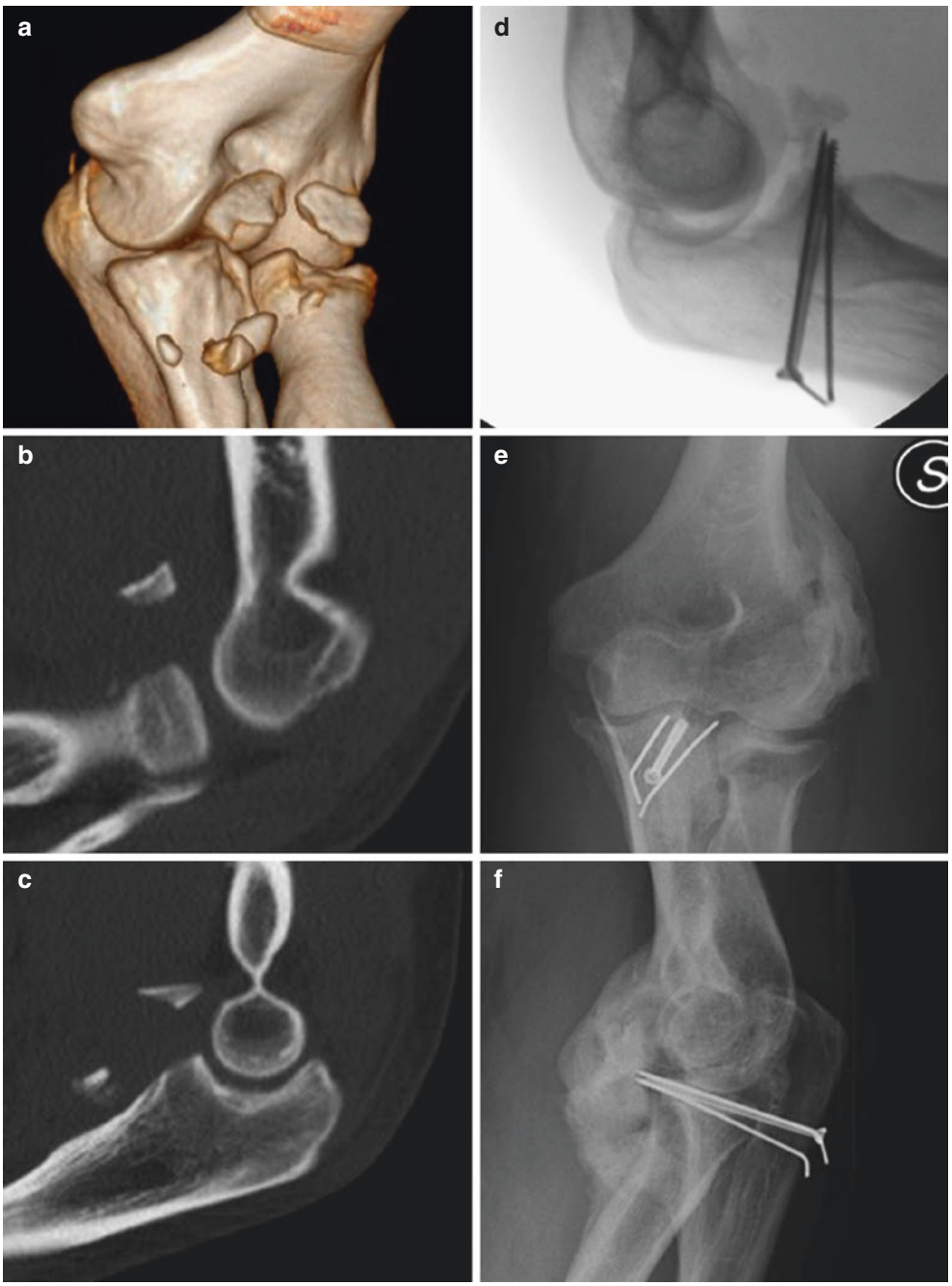


Fig. 16.8 Terrible triad of the right elbow in a 28-year-old patient. Tridimensional and bidimensional CT scan images (**a**, **b**, **c**) of the radial head fracture and of the coronoid fracture. (**d**) Radiographic intraoperative image after arthroscopic removal of the fragments of the radial head and reduction and internal fixation of the coronoid. (**e**, **f**) Radiographic images at 4 months follow-up, showing massive bridging anterior ossification

16.6 Complications

No neurological or vascular lesions were recorded.

There were two cases of postoperative stiffness. One Mason II fracture occurred with extension deficit, which was treated again after 9 months by soft tissue release and arthroscopic removal of the screw. The screw was in place, the fracture was healed, and the stiffness was connected to the reactive fibrosis of the anterior capsule. The soft tissue release enabled the full recovery. The second is the case of heterotopic ossifications as a sequela of the terrible triad treated by arthroscopy. This small-sized radial head fracture was widely displaced; the anterior joint capsule was lacerated and raised with a large fragment of the coronoid. By arthroscopy we followed carefully the path of the radial head fracture, removing the fragments, and performed an ARIF of the coronoid. At the end of the operation the elbow was deemed stable by dynamic tests. Rehabilitation of the patient was begun the day after surgery. Unfortunately, at one-month follow-up, anterior bridge ossifications had formed, with a complete loss of passive movement (Fig. 16.8). That patients needed an open anterior and posterior arthrolysis to gain motion at one year of follow up.

Conclusions

The indications for arthroscopic surgery have become wider and more perfected, over the last two decades, and

Table 16.1

Advantages
– Minimally invasive – Better control of the reduction and stability of the fixation – Draining of the hematoma and removal of small fragments in the recesses – Does not preclude conversion into open surgery
Limits
– Current lack of dedicated instruments (aiming device, screwdriver and long cannulated drill, arthroscopic cannulae – Possible need to have to change the patient's position if open surgery is required – Need for precise selection of the surgical indication, excluding beforehand cases that require repair/reconstruction of the collateral ligaments – Technique still in evolution: although the removal of small articular fragments and radial head excision can also be performed by surgeons with limited experience, conversely, ARIF requires deep knowledge of traumatology and of open and arthroscopical elbow surgery

provided new tools to better address various diseases: one example is the joint fracture treatment which has witnessed the move from surgical debridement to arthroscopic reduction and fixation (ARIF).

The impetus to strive for this difficult but interesting evolution comes from the need to reduce the surgical trauma caused by exposing and reducing articular fractures, which even now give high sequela rates over time.

If 10 years ago ARIF was a future possibility, today it is becoming a reality which, with its advantages and limits (see Table 16.1), is on a par with open surgery.

In this chapter we have tried to summarize the state of the art in the light of our experience. The various surgical techniques described are still not perfectly reproducible, and the surgeon must adapt them to suit each patient. If the feeling is that of a promising road to go down, the two complications that we have highlighted teach us that arthroscopy is also not exempted from the risk of postoperative stiffness. The number of cases is still too small, and more in-depth studies are required to assess the real cost/benefit relationship of arthroscopic treatment of articular fractures.

A strict selection of the surgical indication is indispensable; currently we can indicate the following conditions for arthroscopic treatment:

- Fractures of the radial head: Mason type 2–3 fractures (no combined ligament lesions)
- Isolated fractures of the coronoid
- Really selected cases ot terrible triad
- Fractures of the *capitulum humeri* (no combined ligament lesions)

Only case reports are found for the arthroscopic treatment of combined fractures of the radial capitellum and coronoid, other articular fractures (inter or supra-condyloid), or lesions of the lateral collateral ligament (Shaun Holt et al. 2004). These cases are to be left in the hands of more expert surgeons of the sector while waiting for further technical development and significant results.

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Distal Humeral Fractures in Elderly Patients: Synthesis or Prosthesis

17

Andrea Miti, Dragana Katusic, Eugenio Chiarello, and Piero Piciocco

17.1 Introduction

Distal humeral fractures are uncommon. The incidence is approximately 5.7–6/100,000 per year (Robinson et al. 2003; Court-Brown and Ben 2006); they are about 30% of fractures of the elbow (Webb 2001), which make up to 7% of the adult fractures (Angelen 2005). The aging population has made these kinds of fractures increasingly common (Court-Brown and Ben 2006). A Finnish study showed that in women older than 60 years, the rate was doubled considering the cases in 1970 and those in 1995 (12/100,000 women in 1970 to 28/100,000 in 1995) with an expected tripling in 2030 (compared to 1995) (Palvanen et al. 1998). Due to low bone quality, these fractures show a high degree of comminution of the articular surface and of both columns (Webb 2001; Jupiter and Mehne 1992). The degree of comminution and low bone quality make the choice of treatment controversial and certainly not easy to perform.

Nonsurgical treatment (Eastwood 1937; Riseborough and Radin 1969; Pidhorz et al. 2013) was popular in the 1970s and now is a time-honored attitude. Conservative treatment is considered obsolete, but it still plays a role in patients with very low functional demands or not suitable for surgery.

Nowadays the best choice of treatment between osteosynthesis and prostheses is debated. Open reduction internal fixation (ORIF) is the gold standard in young patients; in elderly ORIF has resulted in less predictable outcomes because of poor bone and soft tissue quality and comminution of the fracture.

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17.2 Nonsurgical Treatment

Conservative treatment is exceptional in distal humerus fracture and also in patients over 65 years old. Several methods have been described: trans-skeletal traction, closed reduction maneuvers, and application of cast or sling.

Advantages of conservative treatment are the lack of exposure of the patient to the risks of surgery and the lowest percentage of vascular and nerve complications. Disadvantages are the length of immobilization period, longer hospital stay in case of trans-skeletal tractions, and higher rate of non-union and mal-union. Techniques like "bag of bones" can be used with short period of immobilization followed by early mobilization. A brachial-antebrachial-palmar cast with a sling-type brace immobilization for 4–6 weeks can be used in patients with poor health conditions and in whom the surgery is contraindicated.

17.3 Surgical Treatment

Distal humerus fractures (DHF) are very challenging to manage for orthopedic surgeons. Improved operative techniques and new implant designs gave better results in treating these kinds of fractures.

An accurate surgical planning is crucial to achieve good results. Assessment of neurovascular status, (especially ulnar nerve), type of fracture and its classification (standard plain radiographs could be insufficient, and a CT scan is helpful), patient positioning in the operating room (prone, supine, or lateral), surgical approach, need of bone grafting, and choice of implants should be considered. The lack of one of these aspects could result in poor clinical outcomes.

The most validated treatments in literature are open reduction internal fixation (ORIF) and elbow arthroplasty (EA).

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17.3.1 Open Reduction Internal Fixation (ORIF)

The goal of ORIF is to achieve anatomic and stable reduction to allow early mobilization. ORIF is indicated in patients with these pattern fractures using AO-ASIF classification: 13A (except 13A2.3), 13B (except B1.3, B2.3, or B3 multifragmentary), and 13C1 (Muller and Nazarian 1990).

Surgery is performed with the patient in prone or lateral position. A sterile tourniquet is inflated. A posterior "universal" skin incision is made (Dowdy et al. 1995). The ulnar nerve is identified and protected. We do not transpose the ulnar nerve routinely. The nerve release is extended from about 7–8 cm proximally and 5–6 cm distally to the medial epicondyle at the origin of branches of the m. flexor carpi ulnaris. In fractures extended more proximally, the radial nerve should be identified and protected.

To gain a good exposure, we usually perform a transolecranic approach because of the greatest exposure of the articular surface (Wilkinson and Stanley 2001). The olecranon osteotomy is V shaped (Chevron) and is performed with a saw and an osteotome, aimed to the bare area of the articular surface of the olecranon. In supracondylar fractures, triceps retracting approach (triceps on) can be performed as described by Alonso-Llames (1972); Kirschner wires and reduction clamps are used to maintain the reduction of the fragments (Fig. 17.1).

Plates can be placed perpendicular as described by the AO-ASIF group (Muller et al. 1991). One plate is placed along the posterolateral aspect of the distal humerus along the lateral column and capitellum. The second plate is placed medially and is contoured around the medial column. Drawbacks of this fixation technique include limited anchorage of the plates on the distal fragments and limited compression at the supracondylar level (Morrey 2014) (Fig. 17.2).

The other possibility is to place plates parallel; this disposition has been described to prove a better biomechanical stability. In fact the linkage of the plates together through the bone with screws creates the architectural equivalent of an arch (Elf et al. 1995). The arch is formed by interdigitation of locking screws passing through the distal fragments from both plates in the sagittal plane. Both the parallel and the perpendicular positions are effective to achieve good stability, but when the fracture is in a frontal level (Coronal shear fractures) that affects the condyle and the epicondyle with or without trochlear extension, the posterolateral plate allows a tight anchor in the distal fragment more difficult with a lateral plate in the parallel plate configuration.

17.3.2 Elbow Arthroplasty

In cases of comminuted fractures (i.e., B1.3, B2.3, C2, and C3), poor bone quality, and in cases of low demands, inflammatory arthritis, or in the case of non-unions of A23 fracture, total elbow arthroplasty (TEA) is a suitable option of treatment. In cases of young patients with a comminuted DHF in which the ORIF cannot be achieved but also in cases of chronic mal-union, non-union, or avascular necrosis of the trochlea with collapse of subchondral bone, distal humeral hemiarthroplasty (DHH) is increasing popularity.

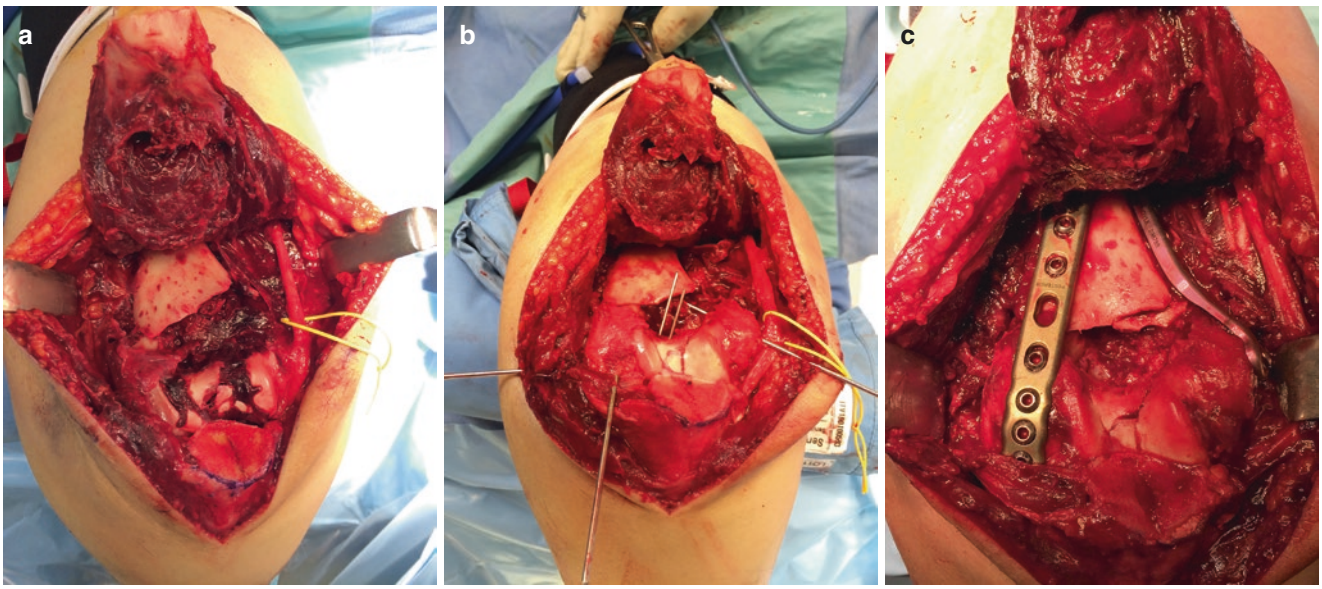


Fig. 17.1 67-year-old male with a 13-C3 left distal humeral fracture: intraoperative photos. (**a**) A V-shaped olecranon osteotomy was performed in order to improve the visualization of the surgical field; the ulnar nerve was previously isolated and protected during the surgery. (**b**) A temporary fixation of the articular surface with Kirschner' wires was achieved. (**c**) Stable and definitive synthesis with a perpendicular configuration of the locking plates



Fig. 17.2 67-year-old male with a 13-C3 left distal humeral fracture. (**a**) AP and lateral preoperative X-rays. (**b**) Four months follow-up. Two perpendicular locking plates were implanted. (**c**) Clinical outcomes at 4 months follow-up

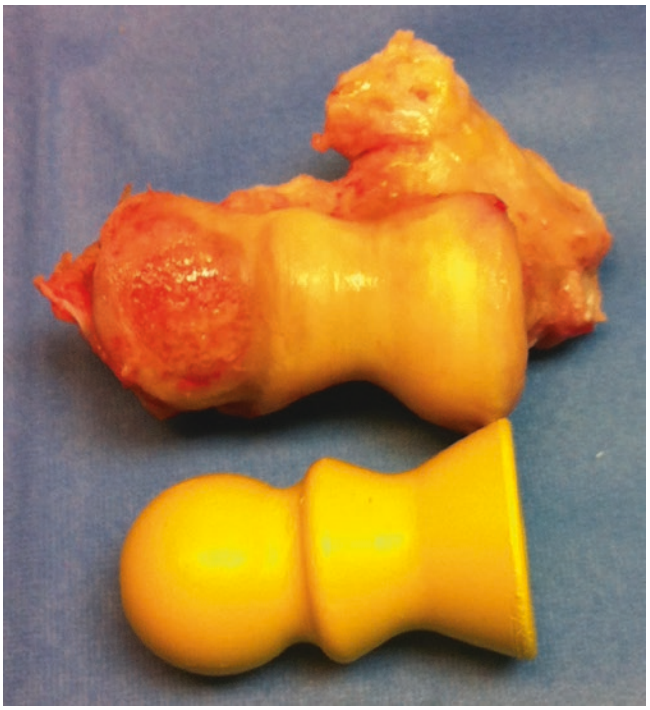


Fig. 17.3 Similarity in size between the articular surface and the prosthetic test

The surgical technique for the TEA is carried out through a posterior skin incision. The ulnar nerve is identified, isolated until the emergence of the branches to the flexor carpi ulnaris, and protected. The approach used is the triceps retracting or "triceps on" according to the technique described by Alonso-Llames (1972). Then the collateral ligaments are cut and basted with sutures for later reconstruction. The bony fragments are removed, and the joint is dislocated medially to avoid traction on ulnar nerve. Subsequently the humeral shaft is broadened with broaches until a good diaphyseal fit is achieved. Thus, the correct size of the humeral component is chosen (Fig. 17.3). Preparation of the ulnar shaft is performed in the same way, but an osteotomy at the apex of the olecranon is required in order to better align the stem to the diaphysis; when the components are chosen, particular attention must be paid to avoid conflicts between the coronoid process and the anterior flange of the humeral component, carrying out a partial osteotomy of the coronoid. The next step is to cement the final components. Before closing with sutures, the ulnar nerve should be evaluated, and in case of compression, it is transposed into a pocket arranged in the subcutaneous adipose tissue.

Prior to considering the use of TEA in fractures, we have to clarify the characteristics of each type of prosthesis. The modern implants could be briefly classified as linked, unlinked, and convertible; for constrained, semiconstrained, and unconstrained, just refer to the degree of congruence and rigidity between the humeral and the ulnar components (Kamineni et al. 2005; Schneeberger et al. 2000) (Table 17.1).

Table 17.1 Models of elbow arthroplasty

Hemiarthroplasty	Unlinked TEA	Linked TEA	Convertible TEA
Latitude, Tornier	Pritchard ERS, DePuy	Latitude, Tornier	Latitude, Tornier
Questor elbow system, Wright	Capitello-condylar, Johnson and Johnson		Acclaim, DePuy
	Souter-Strathclyde arthroplasty, Stryker		
	Kudo TEA, Biomet		
	Sorbie-Questor TEA Wright		

17.3.2.1 Linked Total Elbow Arthroplasty

Linked TEAs (LTEAs) are coupled together through a hinge; these implants cover virtually all elbow pathologies that require an arthroplasty. Among LTEAs, the most popular are the semiconstrained models which allow some degree of varus-valgus tilt for dissipation of forces. LTEA can be implanted in patients with extensive injury to ligaments and capsule and in case of poor bone stock (Fig. 17.4).

Malalignment even of a few degrees can result in abnormal forces and can lead to prosthesis failure, and this is more evident in constrained implants. In semiconstrained models, the enhanced stability supplied by the coupling is provided without transmission of excessive stress to the bone-cement interface (O'Driscoll et al. 1992; Brownhill et al. 2012).

17.3.2.2 Unlinked Total Elbow Arthroplasty

Unlinked total elbow arthroplasties (UTEAs) are not mechanically coupled and rely on matching shapes of the bearing surfaces (Banagan and Murthi 2006).

The rationale of unlinked implants is that there is a sharing of load among prosthesis, capsule, ligaments, and muscles in an effort to decrease stress in articulation and stems; thus, a necessary prerequisite for UTEAs is the presence of adequate ligaments (medial and lateral) and bone stock in which the implant can be stabilized after insertion and muscle balance (flexor and extensor).

Indications for unlinked designs are narrower than linked arthroplasties, but the instability rate is greater because their stability mainly depends on their geometry and surrounding soft tissues rather than the intrinsic constraint of the articulation (Alizadehkhaiyat et al. 2015).

Active infection is an absolute contraindication to elbow arthroplasty. The absence of functioning muscles to move the elbow and a nonfunctional hand are relative contraindications. Unstable elbows with poor ligaments or deficient bone stock should be managed with a linked device. Gross



Fig. 17.4 88-year-old female with a 13-C2 fracture. (**a**) AP and lateral preoperative X-rays. (**b**) Two months follow-up. A linked total elbow arthroplasty was implanted

deformity is an indication for a linked device because achieving precise soft tissue balancing is usually not possible (Morrey and Sanchez-Sotelo 2009).

17.3.2.3 Convertible Total Elbow Arthroplasty

A convertible TEA is a device that can be changed between a linked or unlinked coupling during the surgery procedure.

The choice between an unlinked or a linked configuration is related to the spectrum of pathology that can be successfully addressed by the design. In general it should be considered that the potential for instability is greater with the unlinked implants (Morrey and Sanchez-Sotelo 2009).

Unlinked implants might be selected in the younger patients in whom pain relief is desired and collateral ligaments and joint stability are close to normal with motion being a secondary consideration and for rheumatoid disease with collateral ligament stability present or obtained by implant insertion (Kudo et al. 1980).

Linked implants are preferred when the goal is to improve motion and stability of the elbow (Morrey et al. 1981).

17.3.2.4 Distal Humeral Hemiarthroplasty

Distal humeral hemiarthroplasty (DHH) is "per definition" an unlinked prosthesis and thus must have a high degree of congruency with the radius and ulna to provide stable force transmission through both medial and lateral articular columns; therefore, sizing is crucial for achieving good results but also is required for intact collateral ligaments. The choice to implant a hemiarthroplasty cannot prescind from three anatomic conditions: (1) the extra-articular columns, (2) the collateral ligaments, and (3) the radial head must be intact or reparable.

DHH provides an alternative treatment in younger patients that bridges the gap between internal fixation and TEA in unsalvageable DHF but also in others pathologies.

17.3.3 Linked Total Elbow Arthroplasty Rehabilitation Protocol

The functional range of motion of the elbow is between 30–130 degrees of flexion and 60 degrees of both supination and pronation.

In cases of TEA implanted on fractures, the limitation of pronation and supination is minimized when there were no preexisting articular conditions that had involved the proximal and/or distal articulation, or when the resection of the radial head took place. Therefore, we can expect a complete recovery of the prone-supination in the majority of cases (Fig. 17.5).

If a "triceps-on" approach has been used, the physical therapist needs to respect the integrity of the posterior incision, avoiding stress on the sutures; this is crucial in case of swelling.

Attention must be paid to the cervical spine and shoulder. Often the shoulder could be involved in the same trauma even without fractures. In such cases, the bursa, the rotator cuff, the long head of the biceps brachii, and the cartilage can be injured.

Rehabilitation of the elbow in LTEA performed with "triceps-on" technique is not particularly complicated and does not warrant special finesse. Physical therapy should take place 2–3 times per week but could be subject to specific modifications on a case-by-case basis. During the first 2 weeks after surgery, there could be swelling of the elbow, the forearm, and the hand which has to be treated. The first plan of action is rest in a sling. Active movements of the wrist and hand are strongly suggested. At night the affected area should be placed on the chest to increase circulation. During the day the intermittent use of ice and anti-inflammatory medications help reduce swelling. During the first 45 days, the aim of the rehabilitation is to recover the movement of the elbow. This recovery is progressive and must take place without pain. Range and motion of the shoulder, elbow, wrist, and hand will be done under therapist supervision. No specific measures are necessary concerning the triceps if this has not been severed. The use of a sling is suggested for 30 days, and it should be removed for the rehabilitation therapy. Eventually the brace can be removed at home during the last 15 days. However, outside, it should be used for the entire 45 days.

During this initial period if there is no longer any swelling and the pain is minimal, the patient may use his arm to handle basic daily activities such as eating, washing his face, and getting dressed. The patient must not lift items heavier than 500 g. By the end of the 45 days, movement should be just about normal, generally with a 20° limit extension while the flexion reaches 130°. It is crucial to assess if the restriction in the extension is flexible and eventually susceptible to improvement or if it is stiff (inflexible) and therefore will not improve with rehabilitation. X-rays of the elbow would clear any doubts by showing if there is any evidence of calcification or ossification, which could limit the movement.

If the movement is restricted and does not allow a range between 20 and 130°, then articular stretching is strongly suggested without pain and above all must be executed with caution and never forcefully.

It would be helpful the aid of an articulated brace that would maintain the articulation at maximum flexion and maximum extension, alternating (respectively) between 4–6 h.

The strengthening of the flexor and extensor muscles of the arm and the forearm can be initiated after the first 45 days. This will alleviate the feeling of instability felt by the patient due to the free range of motion of the prosthesis. Normally we are dealing with elderly patients who do not need a specific muscular strength. Therefore, these strengthening exercises should be progressive and light enough to recover the necessary strength to heal and bring the patient to normal daily activities. The strengthening could be done with isometric exercises of the various muscular groups at the intermediate values of the overall movement reached by different arm and forearm articulations, avoiding high-degree isometric contractions.

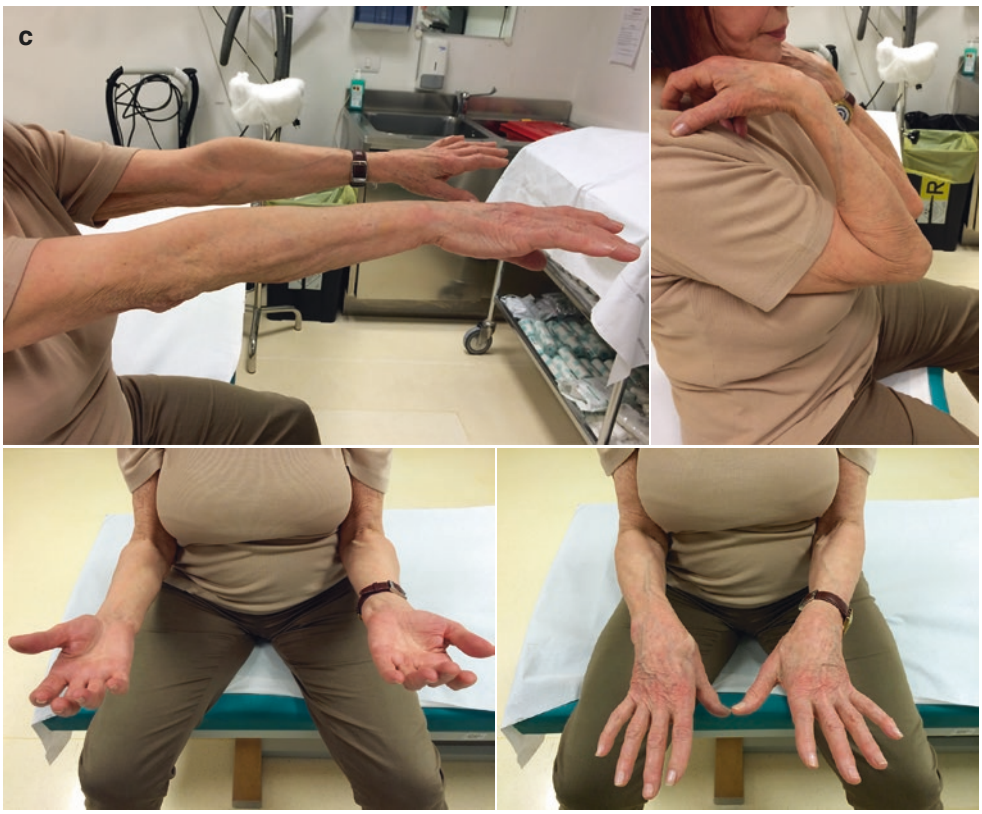
During this rehabilitation stage, it is mandatory to continue articular stretching to further increase movement if it is still limited and to eventually return to normal activities. Patients who had arthroplasty surgery of the elbow cannot lift repeatedly more than 2–2.5 kg and never must carry more than 5–7 kg.

The program will progressively continue for two more weeks in order to further increase the range of motion and to strengthen the muscles.



Fig. 17.5 78-year-old female with a 13-A2 fracture. (**a**) Preoperative AP and lateral X-rays. (**b**) One month follow-up. (**c**) 6 months clinical follow-up

Fig. 17.5 (continued)



If 4 months after surgery the flexion does not reach 120°, the help of static or dynamic braces should be considered. This decision will be made together with the surgeon and after examining the reasons for this restriction.

17.4 Discussion

In literature there is a debate about the best treatment for DHF in elderly people: internal fixation or primary total elbow arthroplasty (Miti et al. 2014). The open reduction internal fixation remains the gold standard for many authors and is described as the first-line treatment for distal humerus fractures in elderly patients. However, in the results using ORIF in patients over 65 years old, the literature shows a very large range of outcomes. Pereles and colleagues (Pereles et al. 1997) in a retrospective review of 12 patients (age, 63–85 years) with operatively managed displaced distal humerus fractures found good to excellent results in 100% of cases. They reported two cases of hardware failure (one required revision), no infections, no cases of postoperative ulnar nerve symptoms, and bony union in all patients at a mean of 16 weeks. On the other side, Srinivasan et al. (2005) evaluated the results of 29 fractures (mean age of patients, 85 years) and compared operative management (21 fractures) with conservative treatment (8 fractures). Although they found that, at a mean follow-up of 42 months, ROM and pain relief were better for patients treated operatively than for those treated nonoperatively, only 57% of cases were judged as having good to excellent outcomes. Egol et al. (2011) compared functional outcomes of total elbow arthroplasty and plate fixation for distal humerus fractures in osteoporotic elbows. Excellent results were reported by Sanchez-Sotelo. The authors described their results using locking parallel plating technique in a series of 34 consecutive patients (Sanchez-Sotelo et al. 2007). There was no hardware failure and just one pseudoarthrosis. Also Egol et al. (2011) reported very good outcomes with a 9% rate of failure in B and C AO/OTA-type fractures. They justified these excellent results with the use of newer locking implants that reduced the number of hardware-failure complications in the osteoporotic bone.

These excellent results represented by a stable, painless elbow, with a functional range of motion, could be achieved by improving knowledge in operative technique. As suggested by O'Driscoll, every screw in the distal fragments should pass through a plate. Every screw should engage a fragment on the opposite side that is also fixed to a plate. As many screws as possible should be placed in the distal fragments. Each screw should be as long as possible. Each screw should engage as many articular fragments as possible. The screws in the distal fragments should lock together by inter-

digitation, creating a fixed-angle structure. And more regarding the type and the position of the plates, plates should be applied such that compression is achieved at the supracondylar level for both columns. The plates must be strong enough and stiff enough to resist breaking or bending before union occurs at the supracondylar level (Morrey 2009).

The use of "lag screw" is not suggested in comminuted fracture of the articular surface. The use of "position screw" must be preferred because it does not compress the fracture and avoids the narrowing of the articular surface (Beingessner and Barei 2012).

In cases with significant metaphyseal comminution at the supracondylar level, two choices can be considered. The first is to resect the comminution and shorten the distal humerus to achieve contact, compression, and union (O'driscoll et al. 2002). A 2 cm shortening is possible without or minimal impact to mechanical biomechanics of the elbow. (Morrey 2015) The second choice in case of a metaphyseal comminution is to bridge the comminution with longer plates.

However, because ORIF in elderly could be technically demanding, some surgeons propose primary arthroplasty as a treatment (Morrey et al. 1981; Morrey and Adams 1995). Conditions at the fracture site often require the use of a lax hinge-type implant, to overcome the bone loss and any potential ligament injuries. Despite the fact that in previous studies the use of semiconstrained implants for fracture management yielded poor results, such as reduced implant survival time and high revision rates (Frankle et al. 2006), TEA has become a popular reconstructive procedure. The most recent studies show that advances in implant technology and surgical technique have led to improved outcomes (Cobb and Morrey 1997; Voloshin et al. 2011). Since then, many groups have published good and even excellent results with these implants (Hildebrand et al. 2000; Gambirasio et al. 2001; Garcia et al. 2002; Frankle et al. 2003; Prasad and Dent 2008; Kraay et al. 1994; Ray et al. 2000; Kamineni and Morrey 2004; McKee et al. 2009; Charissoux et al. 2008). Based on our review of literature, four studies have compared these two treatments in patients above 65 years of age, three were retrospective (Egol et al. 2011; Frankle et al. 2006; Charissoux et al. 2008) and one was prospective (McKee et al. 2009); moreover, a peer-reviewed article (Garcia et al. 2002) was found.

Frankle and colleagues (Frankle et al. 2003) in a retrospective review compared TEA and ORIF outcomes in comminuted and displaced intra-articular fractures in patients older than age 65. Twenty-four women were followed up for a minimum of 2 years. 90% of their TEA outcomes and 33% of their ORIF outcomes were excellent. The author underlined less operative time, for the TEA group 77.9 minutes of average time against 146 min for the ORIF group, and less complication and better recovery of ROM for TEA, and less length of hospitalization 2,92 vs 2,16. As there were one fair and three poor results in the ORIF group and no poor and no fair results in the TEA group, they were led to recommend arthroplasty for patients older than age 65. The same experience was noted.

In a Canadian prospective, randomized, multicenter controlled trial, McKee and colleagues compared ORIF with primary semiconstrained TEA results in complex bicolumn intra-articular fractures in the elderly (mean patient age, 77 years) and found earlier improvement and a lower reoperation rate in the TEA group. Although there was a trend toward improved motion in the TEA group, the mean extension, flexion, and arc of motion of flexion-extension, the difference in outcome scores evened out by 1-year follow-up, and there were no significant differences between the two groups at 2 years. McKee reported a significant decrease of operative time in the TEA group (Charissoux et al. 2008).

In the other studies, both Charissoux and colleagues (Charissoux et al. 2008) and Egol and colleagues (Egol et al. 2011) found no statistically significant difference in clinical outcomes for TEA at least at early follow-up.

We cannot match the results of ORIF vs TEA because of the strict inclusion criteria that lead our choice of treatment and that make the population not comparable.

Briefly in agreement with as postulated by Ali et al. 2010), our indications to perform TEA were:

1. Patients over 75 years old
2. All aged patients with rheumatoid arthritis
3. Patients with limited life expectancies of any age
4. All aged patients with bone disease
5. Patients with elbow arthritis over 60 years old

In our opinion TEA should be implanted also in case of:

1. Patients with post-traumatic osteoarthritis over the age of 60 years
2. Non-union of distal humerus above the age of 70 years

Although there is evidence for carrying out a primary TEA for these complex injuries in an elderly population, many surgeons still prefer to carry out a primary ORIF to avoid the long-term complications associated with TEA. For those who choose ORIF, the reason is because successful plating allows the elbow to maintain a good function in the long term without requiring further reconstructive surgery. Moreover they say that in cases of failure due to non-union, TEA still remains a surgical option. About this we would underline that as reported by Sivardeen et al. that retrospectively compared the results of primary TEA and TEA after failed ORIF, with a mean follow up of 5 years, the patients receiving a primary TEA had a significantly higher MEPS than those having a TEA after a failed ORIF (Sivardeen et al. 2007).

Conclusions

DHFs are extremely difficult to treat, and almost all fractures should be treated surgically after a meticulous preoperative planning; all the patients should be assessed through plan radiographs and CT reconstructions. Also the general condition of the patients is critical in order to choose the best treatment.

Surgeons should have sufficient experience in treating these fractures, and if the fracture is very complex and fixation is considered to be beyond the surgeon's technical experience, serious consideration should be given to onward referral to an elbow specialist unit.

In our opinion internal fixation should be the first choice, and also there is much evidence to support good outcomes in literature, despite the debate about the configuration and the type of plates used. However, it is certain that the use of locking plates has improved the stability that can be achieved with these fractures.

An EA should always be present in the operating theater when performing an ORIF technique as salvage procedure.

Primary TEA is an acceptable option for the management of comminuted bicondylar articular fractures of the distal humerus in elderly patients with poor bone quality and with osteoarthritis and rheumatoid arthritis. In younger patients however, every effort should be made to primarily fix the fractures as the expected life expectancy outweighs the implant longevity, but in case of very comminuted fractures, a hemiarthroplasty can be used.

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Articular Fractures: Treatment and Rehabilitation

18

Susanna Stignani Kantar

As aforementioned, fractures of the elbow are a relatively rare event representing about 2% of all fractures. Of these, however, about 1 in 3 is an elbow intra-articular fracture and, for specialists who deal with the elbow, are not so rare (Kilicarslan et al. 2011)!

Of these fractures, the most common ones involve the distal humerus and the radial head. For the latter, see the next chapter while below we'll discuss about the rehabilitation treatment of the distal humerus fractures.

Often the traumatic event that underlies an intra-articular elbow fracture is also responsible for a damage to the capsular-ligamentous articular components, making orthopedic and rehabilitation treatment more complicated and challenging because there's a large overlap with the problems of instability treatment.

The goal of the treatment of an intra-articular fracture is to achieve fracture union and to restore functionality to the elbow joint. But how can we achieve this goal?

In the recent past, several times it has been attempted to treat distal humerus fractures conservatively with a technique called "bag of bones." It consists of a sling to immobilize the elbow or flexed to 120°and gradually increasing extension in the subsequent 3 weeks or flexed to 60° (or 90°) for 2–3 weeks and then starting the active recovery of elbow range of motion (ROM) (Ring and Jupiter 1999; Nauth et al. 2011).

The best results obtained include elderly patients (64 years and older) who have recovered a range of motion in flexion-extension of about 116° (Brown and Morgan 1971).

This result, however, is quite far to satisfy the younger patients, those active, or even the "our days" elderly people who often are not only independent in their daily activities but still eager to pursue their favorite sport or hobbies such as dancing.

In this population then, goal of treatment will be the recovery of the widest painless range of motion as possible, a stable elbow, as well as to reduce the potential development of osteoarthritis.

Given the anatomical complexity of the joint and the ease of the periarticular soft tissues to contract and stiffen, it is clear that currently the treatment of choice of these fractures is surgery, leaving conservative treatment only for the undisplaced fractures or for people who have a very low functional demands or conditions that contraindicate surgery.

There is fair evidence (grade B of recommendation) to support the operative management of all displaced fractures of the distal part of the humerus in patients able to tolerate anesthesia (Nauth et al. 2011).

The goal of surgical treatment is to obtain an anatomic reduction of the fracture articular surface, to obtain an internal fixation rigid enough to allow for an early motion, and to prevent a potential subsequent arthritic degeneration of the joint (Aksoy et al. 2010).

Is known that to maintain a prolonged elbow immobilization (over 3 weeks) means exposure to an increasingly risk of stiffness (O'Driscoll et al. 2003).

We can decide to accept this risk if it has not been possible to obtain a stable fracture fixation or if we have to respect defined times and work plans accordingly to surgical procedure associated (as in case of ligament reconstruction).

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To make the rehabilitation treatment of elbow intra-articular fractures appropriate and effective, is necessary that physiatrist and therapist are aware of many clinical informations about that specific patient and fracture:

- Mechanism of trauma: knowing the trauma modality can help us to assume any potential damage to other anatomical structures and then act in a cautious manner on them (e.g., a fall upon an elbow flexed between 60° and 90° probably causes an olecranon fracture associated with an anterior dislocation; a fall upon an elbow flexed between 30° and 45° will put at risk the base of the coronoid while the tip of the coronoid will most probably fractured with elbow more extended) (Rao et al. 2014).
- Surgical approach used by the surgeon for fracture fixation: depending on the approach, surgeon may insult anatomical structures that will then be protected (e.g., the extensor mechanism in the case of triceps splitting or Bryan-Morrey approach).
- Type and stability of the synthesis: if fixation is not stable, time for joint recovery lengthen because we must wait at least an early bone healing.
- Any additional surgical procedures: fracture synthesis can be associated, for example, with joint replacement of the radial head or a ligament reconstruction (e.g., in case of reconstruction of the lateral collateral ligament, we will avoid any maneuver which may cause elbow varus stress, and we will keep forearm pronated during movement). Indeed are the associated lesions themselves that determine the final rehabilitation program.
- The state of the periarticular soft tissues: together with fracture, it may occur nerve or muscle damage, which in turn will impact on our subsequent treatment choices or on whether or not to use certain instrumental therapies.

Only with these informations, it can be achieved a real custom-tailored rehabilitation program safe for the patient. So it is crucial a continuous collaboration among the different professionals figures who will take care of the patient (surgeon, patient, and physiotherapy team).

To restore functionality to the post-surgery elbow, the first aim of the treatment is the range of motion (ROM) recovery. In our experience, if the fracture is stable, ROM exercises have to start in the first week post-surgery in an active-assisted or gravity-assisted way, in a painless range of motion, and with the scapula stabilized (very useful is the supine position).

It is important to emphasize that there is a lack of robust evidence to inform on the timing of mobilization, and specifically on the use of early mobilization, after nonsurgical or surgical treatment after elbow fractures (Harding et al. 2011).

We prefer that the patient wears an elbow articulated brace at 80–90° of flexion to protect the synthesis for about 3 weeks during the day (Fig. 18.1). The flexed elbow position is that of greater comfort for the patient: in flexion, the articular capsule has its increased capacity, and therefore, the intracapsular pressure is minimal. This means less pain for the patient.



Fig. 18.1 Post-surgical patient with elbow articulated brace at 90° of flexion to protect the bone synthesis (For the courtesy of Di Giacomo S., PT)

During the night, the patient wears an extension splint to protect the posterior soft tissue and triceps insertion (see below).

About how to rotate the forearm instead depends on associated injuries: in the absence of other injuries, we prefer to maintain a neutral forearm position because it is usually very well tolerated by the patient.

If surgery also provides the lateral collateral ligament (LCL) surgical repair, then the forearm will be maintained in pronation position to protect the suture and to ensure greater stability to the elbow by tensioning the extensor-supinator muscles and the medial ligaments complex (Fig. 18.2).

This position is maintained during the extension exercises of the elbow up to about 6 weeks after surgery. Active supination is allowed with the elbow flexed to 90°. The opposite is true in case of medial collateral ligament (MCL) associated repair. If both ligaments have to be protected in the postoperative period, forearm will be maintained in neutral position while in brace.

As we know, starting moving quickly, an articulation brings with it many benefits: it improves hemodynamics



Fig. 18.2 Post-surgical patient with elbow articulated brace at 90° of flexion and pronated forearm to protect bone synthesis and LCL suture (For the courtesy of Di Giacomo S., PT)



Fig. 18.3 Important elbow edema and hemorrhage (For the courtesy of Severini G., MD)

district which helps drain post-surgical edema, reduces intra-articular adhesions development, and promotes healing of cartilage tissue.

For this reason, we have to solve joint pain and edema first as these represent a real obstacle for an early rehabilitation (Fig. 18.3).

To do this, keep the limb raised and the use of ice (or cryotherapy) are always two cornerstones of our treatment and very easy to place in their simplicity.

Nonsteroidal anti-inflammatory medications and analgesics opioids are important in the immediate post-surgery period.

Some authors have also proposed the use of so-called multimodal analgesia: it takes advantage of using the additive or synergistic effects of different classes of analgesics to achieve of sufficient analgesia with fewer adverse effects of each one (Lee et al. 2013).

We can combine drugs with both manual and instrumental techniques such as lymph drainage or tecar therapy in the capacitive modality and in a thermal way (that is, at low power levels); always exploiting the latter mode, it is possible to obtain also a sedative-analgesic effect on the treated area given the numerous biological effects induced on the tissues (e.g., endorphins release a faster oxygen dissociation of hemoglobin and its greater availability…). It's a good approach to apply a pressure bandage at the end of therapy to maintain the obtained effect.

Recently another type of tape increasingly used is the kinesio tape in the so-called "fan" modality.

Even a delicate soft tissue and scar manual mobilization is useful to facilitate the pain resolution and tissue healing by increasing collagen tissue extensibility (reducing its viscosity) and by reducing muscle spasms and contractions.

Nowadays, to relieve pain and decrease edema, numerous instrumental therapies are available: TENS, ultrasounds, iontophoresis with iodine, and SIT therapy, and in our opinion, every therapist should choose to use freely the one he is most familiar with.

Another very effective way to drain edema is to do the patient a work of active muscular contraction. Then, as soon as the pain allows, patient also introduces elbow active movements (also this usually occurs within the first post-surgical week). Active hand and wrist movement starts immediately after surgery (McCarty et al. 2005).

Even shoulder active movement is granted immediately, but in this case, we have to alert the patient to avoid an internal or external rotation excess: excessive shoulder external rotation creates varus forces on the elbow that lead to excessive stress of the lateral structures and vice versa for shoulder internal rotation. These positions are therefore to be avoided for the first 4–6 weeks after surgery.

Moreover, a slow but sequential activation of agonist and antagonist muscles stimulates tendon receptors and proprioceptive corpuscles of the joint resulting in a further analgesic action. Active movements recruit intra- and extrafusal muscle fibers with a consequent inhibition of the antagonist muscle co-contraction.

Finally, to recruit as soon as possible, the elbow dynamic stabilizers with active muscular contraction helps to stabilize the joint and allows for a safer rehabilitation.

Even the elbow passive movement is useful to promote soft tissue drainage because it raises and lowers the periarticular hydrostatic pressure creating a pumping effect that moves fluids away from periarticular soft tissues.

In our clinical practice, elbow joint motion recovery starts in an active way, and we usually don't use the continuous passive movement machine because we prefer to personally monitor patients and make them perform exercises under the direct therapist's supervision.

Theoretically the exercises for joint ROM recovery can take place in both flexion-extension and pronation-supination, but, as mentioned before, if the fracture of the distal humerus has been synthesized by a triceps-splitting or a Bryan-Morrey triceps-reflecting approach or through olecranon osteotomy, then initially we must protect the triceps insertion or the osteotomy.

In this case, early mobilization will be active assisted for flexion but gravity assisted for the extension, while pronation and supination can be performed actively with the elbow flexed to 90° because in this position, the elbow is usually stable irrespective of forearm rotation (Fig. 18.4).

If instead the triceps has been inviolated, also active extension and flexion exercises can be immediately performed.

It's extremely important that exercises, once started, are performed multiple times during the day and every day.

We think that patient should have a primary role in post-operative rehabilitation and even any lack of motivation, especially in older patients or in patient with cognitive deficit, may impair results despite successful fixation.

If the surgeon is not able to obtain a fracture stable internal fixation, patient has to wait to move the elbow until at least the first signs of fracture healing are evident on X-ray. In this case, the times described above lengthen, and the risk of stiffness highly increases too, but it is preferred to risk a stiff elbow (the surgeon can treat it in a second time) than an unstable elbow or a fracture healed in the defect.



Fig. 18.4 Gravity-assisted elbow flexion

When on X-ray, we can appreciate at least an initial fracture healing (after about 4–6 weeks after surgery that is in the remodeling phase of healing), and the surgeon confirms elbow joint stability; we can allow the patient motion against resistance, begin passive motion in all directions and be more aggressive with ROM exercises eventually even using a night splint in elbow extension or flexion depending on which movement we need to recover mostly (Figs. 18.5a–d, 18.6a, b, 18.7, and 18.8).

Whenever surgical approach involves the reinsertion on to the olecranon of the triceps tendon, we have to protect the repair for the next 4–6 weeks post-surgery, teaching the patient to avoid resisted extension for 4–6 weeks.

In our clinical practice, we rarely use static progressive splint between work sessions as we have often observed poor compliance by the patient, irritative tissue answers with pain recurrence, and subsequent slowdown of our work or an "incorrect" use and management of the splint that, for fear of pain, is not maintained in the right angle suggested.

We use for this purpose the so-called low-load prolonged stretching in order to regain the last degrees of flexion and extension (Figs. 18.9, 18.10, and 18.11). Patient scapula and humerus should be stabilized with forearm in neutral rotation preferably.

Often stretching is preceded by instrumental therapies able to increase the temperature of the joint to be treated in order to facilitate the subsequent elongation, such as continuous US on the anterior capsule or tecar therapy. In fact heat decrease muscle spasm and pain and increase blood flow and collagen extensibility.

Some authors (and it's becoming increasingly popular) perform stretching after axillary brachial plexus block was applied to the patient to be sure that he does not feel pain, does not diminish the treatment compliance, and therefore does not trigger the vicious circle: pain-immobility-stiffness.

Personally we don't use this method again probably for an overcautious attitude. In fact we believe that the possibility of exceeding the maneuvers is always a "danger around the corner" even by experienced therapists and because we think that the pain still remains a feedback-symptom of the treatment trend and not only an obstacle to it.

To sum up, we agree with Aksoy and with literature recommending active motion in the early post-surgical period while passive movement is delayed after the fifth, sixth post-operative week and passive stretching exercises even later (Aksoy et al. 2010).



Fig. 18.5 Different positions and techniques for passive elbow ROM recovery. (**a**–**d**): flexion recovery



Fig. 18.6 Different positions and techniques for passive elbow ROM recovery. (**a**, **b**): extension recovery



Fig. 18.7 Different positions and techniques for passive elbow ROM recovery. Pronation recovery

When the fracture is nearly healed, we can introduce Maitland joint mobilization (useful to reduce muscle spasm, reduce pain, ROM recovery if immediately followed by active or passive joint movements) that instead we will never do in case of unstable elbow. They are also usefully preceded by heat application (Fig. 18.12).

Other manual therapy techniques used in rehabilitation for this purpose are mobilization with movement (Mulligan technique) and joint glides.

For this purpose in the literature is also described the use of pulsed shortwave diathermy which also seems able to inhibit sympathetic activity (Draper 2011).

Oscillatory joint movements has instead an important proprioceptive function (Figs. 18.13a, b and 18.14a, b).

Dedicating our effort in joint recovery from the early stages of rehabilitation and continue throughout all the rehabilitation period is crucial as we have seen that most patient recovery occurs within the first 6 months post-surgery. Mainly our efforts will be directed to the recovery of flexion that is the most important movement to regain a functional elbow and also the one that recovers more slowly than others (Giannicola et al. 2014).

Together with motion recovery, we have to proceed also with recovery of muscle strength and not only of the muscles around the elbow but of all upper limb muscles.



Fig. 18.8 Different positions and techniques for passive elbow ROM recovery. Supination recovery (For the courtesy of Martinez Gonzales A., PT)



Fig. 18.9 Different possibilities of low load prolonged stretching to recover elbow extension: gravity assisted

Exercises for extensors and flexors of the wrist and fingers (i.e., the elbow dynamic stabilizers) reinforcement may start after 3–4 weeks post-surgery if their anatomy is intact and accordingly to patient tolerance.



Fig. 18.10 Different possibilities of low load prolonged stretching to recover elbow extension: with an elastic band



Fig. 18.11 Exemple of low load prolonged stretching to recover elbow flexion

Light muscle and endurance strengthening exercises for elbow flexor and extensor, forearm rotators, and shoulder muscles are started about 8–12 weeks after surgery (Pipicelli et al. 2011).

Strengthening of elbow muscles, periarticular muscles, and those of the whole upper limb including scapulothoracic muscles follows a classic rehabilitation program: initially reinforcement will be isometric then isotonic concentric, eccentric, and ultimately plyometric for sport or work reconditioning activities of the patient. The work is done in a closed kinetic chain pathway first and then open. In each patient, especially if he's active in sport, an adequate part of the treatment will be dedicated for the "core" recovery, essential to have a "stable platform" on which the upper limb is "grafted."



Fig. 18.12 Maitland method for joint mobilization (For the courtesy of Martinez Gonzales A., PT)

During the elbow rehabilitation phases described above, since our staff has the opportunity to work in facilities equipped with rehabilitative tanks, we use hydrotherapy as much as possible. Before the patient dives into the water, we prefer to wait until the surgical scar is completely healed and that the scabs definitely fell which happens on average after 3 weeks postoperatively. We do not use hydrophobic patches since they are often proved unreliable because they break away from the skin or leave water infiltrate, and we don't want to run the risk of skin breakdown and/or to delay the time of wound closure thereby exposing the patient to the risk of infection already high after surgery.

Although this is not the place to talk about hydrotherapy and the many advantages it offers as they will be treated in detail in a specifically dedicated chapter, however, we can still say that we always suggest to our patients to start muscle reinforcement in water as this environment offers a great help in performing this recovery in a gentle and safe way as well as is less painful for the patient (Figs. 18.15a, b, 18.16, and 18.17a, b).

Usually the patient also performs in water part of joint recovery: first actively from when the scabs fall and the scars are closed up to the maximum ROM obtainable with elbow passive mobilizations. Then patient complete the recovery in a "dry" environment.

Finally hydrotherapy also shows an ideal environment, because of its intrinsic characteristics of "unstable" environment, for the proprioceptive recovery which is a cornerstone of the rehabilitation process (Fig. 18.18).

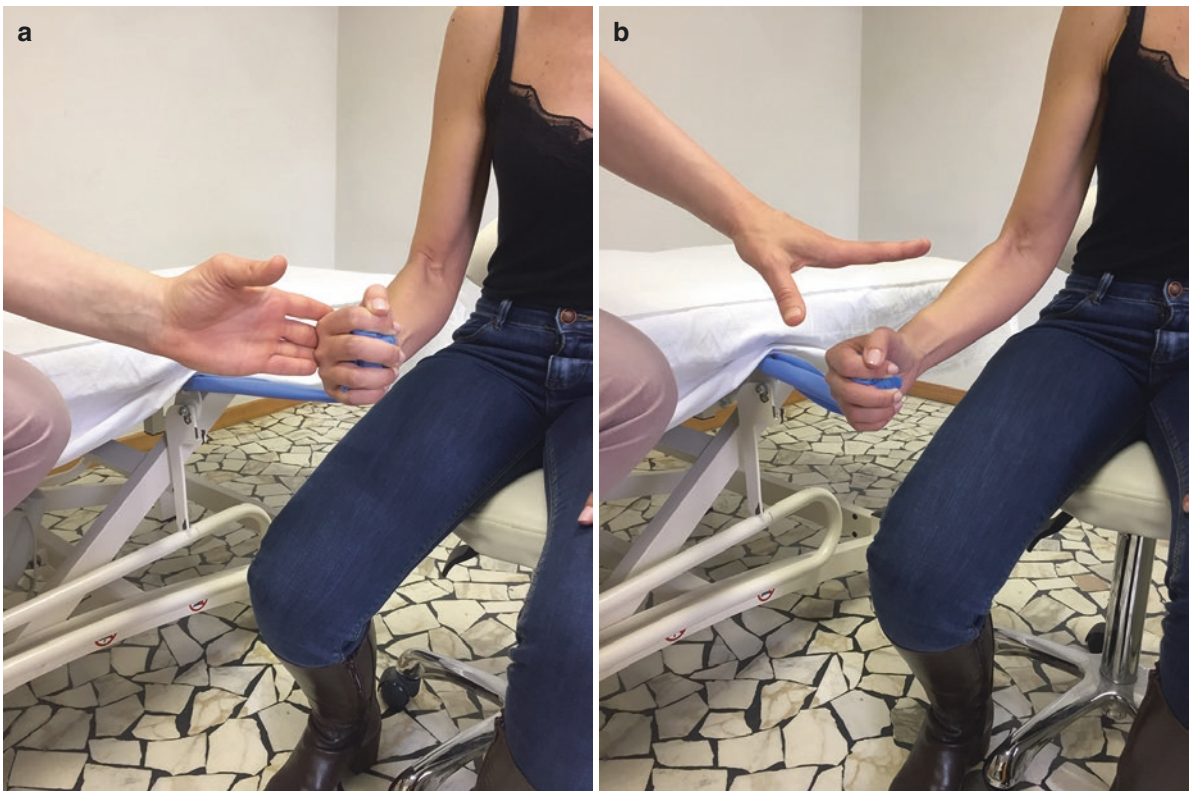


Fig. 18.13 (**a**, **b**) Examples of elbow rhythmic stabilization exercises using an elastic band



Fig. 18.14 (**a**, **b**) Examples of elbow "hand-free" rhythmic stabilization exercises

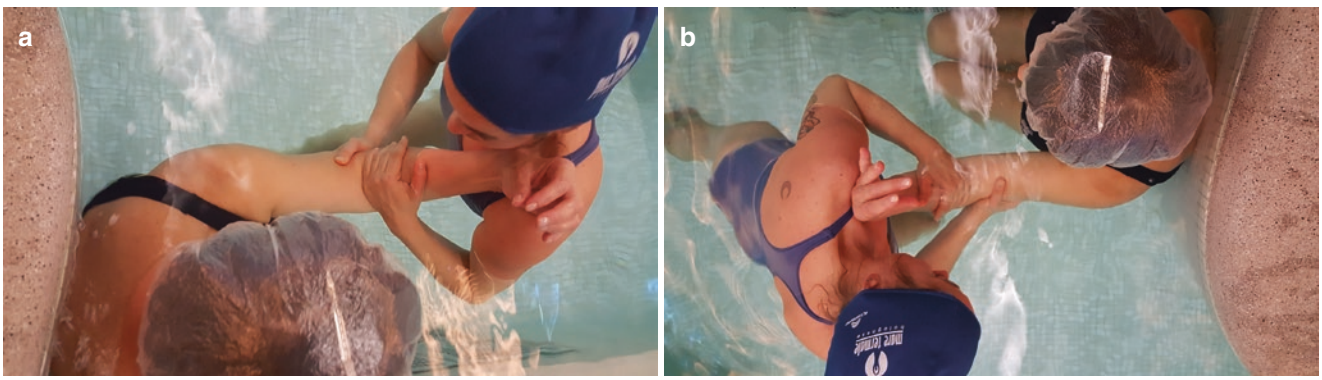


Fig. 18.15 (**a**, **b**) Examples of elbow water-therapy exercises: flexion\extension passive ROM recovery

During the discussion, the term "proprioception" has already been mentioned several times, and in fact the proprioception recovery actually begins very early; for instance, the action of resistive diathermy associated with active-assisted and against resistance physiotherapy that maybe we are performing for other purpose also promotes neurofacilitation for inhibitory action on joint mechanoreceptors and nociceptors.

The extensive damage of the muscle (muscle spindles provide feedback in response to voluntary movement or unexpected loads so provide to position sense), tendon (believed to provide sense of tension above all during passive motion), ligament, and skin (with its rich afferent innervation and overlying muscles and tendons that are moving), depending directly on injury or secondly on surgery, is one of the major factors disturbing proprioception.

In addition, the detachment and the suture of these structures from their natural insertions compromises their physiological length and the proper functioning which in turn creates a disturbance on the feedback and feedforward mechanisms responsible of neuromuscular control, joint position sense, and dynamic joint stability (Lubiatowski et al. 2014).

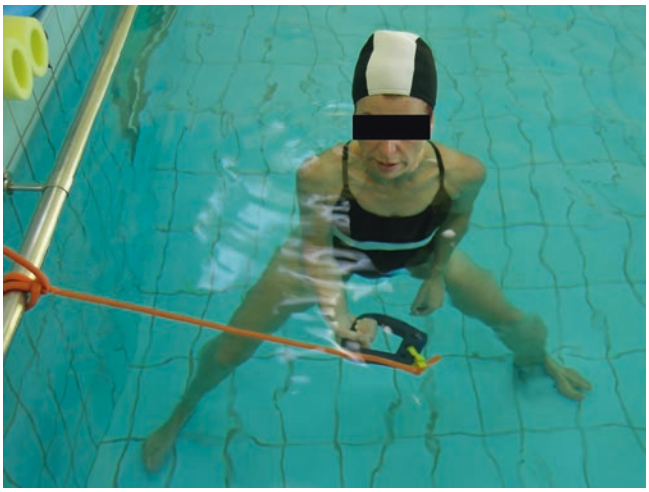


Fig. 18.16 Examples of elbow water-therapy exercises: epitrochlear muscles reinforcement



Fig. 18.18 Example of elbow water-therapy proprioceptive exercise

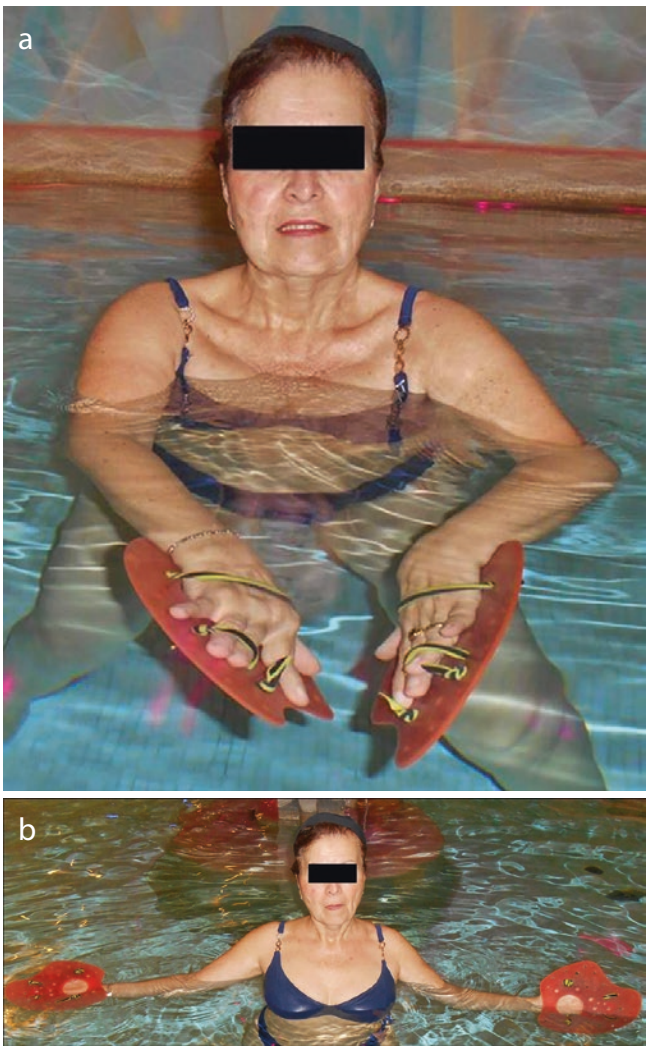


Fig. 18.17 (**a**, **b**) Examples of elbow water-therapy exercises: pronation/supination active ROM recovery with reinforcement

Therefore, restoring a good and stable anatomical environment with surgery alone is not enough to ensure also the functionality of that anatomical region. A good functionality depends precisely on the neuromuscular control, joint position sense, and dynamic joint stability, and therefore, ultimately, it depends on a proper functioning of the proprioceptive system.

Loss of proprioception disrupts inter-joint coordination of a given anatomical segment that is necessary to produce a spatially accurate multijoint movement, harmonic and finalized to solve a certain task.

Coordination is lacking for the loss of the right timing and degree of muscle activation necessary to recruit muscles acting on the joint (Sainburg et al. 1993).

The recovery of this capacity is a defining moment of the rehabilitation program, and the best exercises to improve proprioception are rhythmic stabilization, oscillatory exercises with hand or other devices, and plyometrics exercises (Fig. 18.19a–g). Some authors propose vibration training (low amplitude and frequency and for short time) to improve position sense providing additional afferent stimulation (Tripp et al. 2009).

Some studies have shown that the elbow joint position sense can be altered by the long over-eccentric training because muscle receptors seem to become less sensitive so the patient perceives to generate more power than he actually generates (Walsh et al. 2004; Brockett et al. 1997).

Even muscle fatigue has a negative effect on the sensory motor system because fatigue hinders the normal functioning of muscle mechanoreceptors reducing responsiveness. The sensory system recovers in about 10 min, and for that we must take into account when we set our working sessions especially in the later stages of rehabilitation (Tripp et al. 2007).

As the dominant limb bases its function on the view rather than proprioception (unlike what the non-dominant limb does), it follows that when this one is to be injured, our atten-

tion to proprioceptive recovery has to be even greater. Moreover left arm has a "proprioceptive advantage" with respect to the right one because basis for proprioceptive performances lies mostly in the right cerebral hemisphere (Goble 2010).

To improve proprioception elbow position sense recovery, we agree with authors who state about the importance of skin tactile receptors, and sometimes we ask the patient to perform exercises with a compression bandage worn to the upper limb (Khabie et al. 1998).

Skin and joint receptors are mainly active toward extreme ROM angles (this is presumed to be a protective mechanism to maintain joint movement within a physiological range) that is, those angles in which the view contribution is less. For this reason, we have to perform exercises in a cautious manner but using all angular combinations of the upper limb joints (Fuentes and Bastian 2010).

As described for the intra-articular fractures of the distal humerus can be applied generally for the treatment of all intra-articular elbow fractures even though some special measures have to be taken.

In the rare distal humeral coronal plane fractures, surgeon uses a lateral Kocher approach for the isolated capitellum fractures and for the fractures eventually extended to the trochlear ridge; instead a posterior approach is preferred for the fractures of both the capitellum and trochlea. In the



Fig. 18.19 (**a**–**g**) Examples of "dry" elbow proprioceptive exercises

Fig. 18.19 (continued)



lateral approach, the wrist extensors origin and the LCL (when intact) are elevated first and sutured to the lateral epicondyle after, but it is true that 40% of these fractures have an associate injury of the LCL (Lee and Lawton 2012).

For this reason, we have to protect the lateral structures.

The problem in coronal shear fractures management is that the trochlea is a very important structure for elbow valgus stability during the whole flexion arc even when all the other elbow stabilizers are healthy unlike the capitellum does. Then rehabilitation treatment must very careful to avoid fixation damage because a risk of residual posterolateral rotatory instability of the elbow is high (Sabo et al. 2010).

Fractures that involve the lateral trochlear ridge are therefore the most dangerous for the risk of potential residual instability.

Usually in type I e II fractures accordingly to Dubberley classification, ROM recovery can start immediately after surgery because pain and swelling are limited; instead in type III fractures, the elbow is rested for 7–10 days in a sling with 80–90° of flexion and pronated forearm then active and active-assisted ROM recovery is started with forearm in pronation. Extension is limited to –20° for the same period because full extension creates unnecessary shear forces in the site of the fracture. Patient is alerted to avoid active supination for the first 4 weeks post-surgery not to stress the lateral elbow repaired structures.

An important limitation of flexion and extension and residual pain are the most common complications of this kind of fractures; instead forearm rotation rarely is affected (Mehdian and McKee 2000).

Even coronoid elbow fractures are rarely isolated injuries and therefore rarely are treated in a conservative way. If the fracture involves only the tip (that is less than 50% of the coronoid) and the fragment is not displaced (type I fracture), the elbow is immobilized in a sling at 90° of flexion for 4 weeks than ROM recovery is performed.

If the fracture is surgically fixed, elbow splint has a limited extension of about 40–60° initially: as the elbow movement comes close to full extension and the more the stress under vertical load is mainly distributed on the anterior part of the humero-ulnar joint. Extension will be increased of 10°/week. Sling is worn for about 4–6 weeks, and active-assisted ROM will start depending on patient tolerance with the previous precaution. Pronation and supination and are quite safe if done with the elbow flexed to 90°.

During rehabilitation, we must keep in mind that:

- Coronoid is a key stabilizer to elbow varus stress thus contributing more to stability in extension than in flexion.
- If the fracture involves more than 50% of the coronoid, then even the anterior band of the ulnar collateral ligament that insert on it will be damaged and then sutured during surgery so varus stress on elbow joint (shoulder abduction) has to be avoided for at least 1 month after surgery.

Moreover, since coronoid receives much of the axial load on the elbow between 60° and 105° of flexion, we'll dedicate maximum attention to avoid any hazardous position for the patient until Rx fracture healing.

Coronoid resists to the stress of biceps, triceps, and brachialis muscles which draws the elbow join backwards (Wang et al. 2009) so muscle strengthening exercises are usually not allowed for up to 8–10 weeks.

Olecranon fractures are always intra-articular.

If an olecranon fracture is synthesized, we must limit the elbow maximum extension and flexion because the tricep muscle inserts on it.

Our approach will be different according to the synthesis performed by the surgeon: in case of a tension band fixation according to AO technique, the distracting (tension) force of the triceps is converted into a dynamic compressive force at the articular surface so we allow a cautious active extension work.

If the fracture is comminuted and it is synthesized with plate and screws, then the active extension is avoided, and we proceed only with passive elbow motion because it generates less distraction forces at the fracture site.

If fracture fixation is weak, then flexion will be limited to about 100 ° and increased of 10° of flexion/week.

In the case of fragment excision and triceps advancement, the elbow is immobilized in 45° of extension for 4 weeks increasing 10° of flexion/week as in the previous case. Resistance exercises should be delayed until approximately 12 weeks.

Undoubtedly intra-articular fractures of the elbow represent a great challenge not only for the surgeon but also for the physiatrist, and unfortunately the end result is still often disappointing.

In fact, despite a good fixation and fracture healing and all our efforts to recover ROM and muscle strength, a residual flexion stiffness is still unfortunately very common after this type of fracture: up to 25% of distal humerus fractures result in elbow stiffness (Kim et al. 2005).

Surgeon, physiatrist, therapist, and patient in fact have to be aware that a residual deformity of the humeral articular joint surface is unfortunately quite common after open reduction and internal fixation of the fracture, and this will limit the anterior translation of the trochlea with respect to the humeral shaft: this loss of translation is one of the contributing factors for an elbow flexion limited recovery. This limited flexion cannot be restored even after capsulectomy (Brouwer et al. 2009).

Knowing this in advance, the goal of our treatment is to restore a ROM which is at least functional as indicated by Morrey (30–130° of flexion–extension) and painless.

Also the recovery of elbow flexion/extension muscle strength is often deficient, as shown by O'Driscoll, and is around 75% of the strength contralateral elbow on average.

For young patients or for non-sedentary people, this can represent a real disability, since it often does not allow a return to a pre-lesion level of activity (O'Driscoll et al. 2003).

In conclusion, in the treatment of elbow intra-articular fractures, we cannot avoid to mention the fact that high-energy trauma with important hemarthrosis or trauma that are associated with traumatic brain injury are the most predisposing injuries to the risk of elbow heterotopic ossification (HO) development.

Studies have shown that presence of an AO C3 fracture type was significantly correlated with both the presence and size of HO and that even surgical approach might play a role because incidence of HO seems to be greater in fractures fixed with an olecranon osteotomy approach (Abrams et al. 2012).

Rehabilitation treatment, obviously, nothing can do against this potential cause of extrinsic rigidity nor will prevent neither treat it. However, it is essential that we always keep in mind this possibility every time that treatment is not giving the expected results particularly if the situations mentioned above are present.

Since HO are present on radiographs obtained 2 weeks postoperatively in 86% of patients (Abrams et al. 2012), it is our responsibility to stop the treatment, warn the surgeon, and exclude the presence of a HO since forcing a mobilization in these cases can result in devastating consequences for the patient.

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Rehabilitation After Elbow Prosthesis

19

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19.1 The Rehabilitation of the Prosthetic Elbow

19.1.1 General Principles

Historically, the elbow joint underwent later to the prosthetic replacement in comparison to other articulations because of its complexity. The indication refers to primary or secondary elbow arthrosis, fractures, and rheumatic diseases. Primary elbow arthrosis affects mostly 50-year-old male, and the main risk factor is the use of upper limb in repetitive activities, such as manual labor or sport (mason, hydraulic, tennis player, etc.); often ulnar nerve compression syndromes are associated, for example, the IV and V fingers of the hand tingling (paresthesia). Post-traumatic arthrosis is a fearful articular elbow fracture sequelae and is more frequent and characterized by worse pain and stiffness.

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In the elderly patient, fractures of the distal humerus often are comminuted because of the poor quality of the bone. In this kind of fractures, it is difficult to obtain a stable osteosynthesis to allow an early motion and a valid functional recovery. An immediate prosthetic replacement represents a reliable alternative to achieve this aim, requires a minimal rehabilitation treatment, and has a low percentage of complication (Morrey 2002).

In rheumatic diseases, elbow joint is characterized by the presence of a weak bone, diffuse erosions, subchondral bone cysts, and articular cartilage destruction. This progressive structural joint degradation could be solved by prosthesis replacement but requires a particular cautious and a prolonged rehabilitation approach.

There are two elbow prosthesis models, the unlinked and the linked ones.

By definition, the prosthetic elbow has a greater intrinsic stability with the linked implant in comparison to the unlinked one. The latter type, due to its particular design, is at lower risk of mobilization but has a lower intrinsic stability and consequently requires the collateral ligaments to be intact.

Pain resolution is a goal that can be reached with both prosthetic designs.

Unlinked prosthesis is chosen by the surgeon because of their better results in terms of ROM recovery, while the linked ones allow an elbow ROM recovery between about 20 and 130°. Unfortunately after an unlinked prosthesis model implant, the patient could present an extension deficit too since this system requires a longer immobilization period leading often to stiffness.

This is the reason why when we are in the presence of a severe articular deformity, elbow stiffness, and great instability (as in the most severe rheumatic diseases), we usually chose a linked prosthesis implant.

The surgical approach is always posterior access and can be performed with or without the detachment of the triceps insertion. In the first case, the rehabilitation treatment is more painful, and the flexion movement is restricted at the

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beginning. The same thing applies in the rare cases of trans-olecranon osteotomy: we have to avoid excessive elbow flexion and resisted work of triceps until bone healing has taken place.

Multiple factors influence the prosthetic elbow rehabilitation, as following: patient's pathology, implant used, approach performed by the surgeon with eventual triceps tenotomy or trans-olecranon osteotomy, stability obtained during the surgery, and ulnar nerve involvement. Likewise, the clinical condition of the patient, age, and activity level are fundamental: often, in very active patients, particular recommendations are necessary to respect the restrictions and prevent the prosthetic joint overuse (Szekeres and King 2006).

The prosthetic elbow rehabilitation consists of different phases, and it is not possible to proceed to the next phase if the goals of the previous one are not reached, always respecting the biological tissue recovery (Wilk et al. 1993). Rehabilitation treatment should be set considering the anatomo-functional characteristics of this joint and the modifications caused by the pre-existing pathology, surgical trauma and prosthesis replacement to the ROM, muscular tropism, and neuromotor control. In the rehabilitation planning, the information sharing between all members of the team is essential: orthopedic surgeon, physiatrist, and physical therapist (O'Driscoll 2001). We can distinguish three different phases: preoperative, early postoperative, and late postoperative phase.

19.1.2 Preoperative Phase

The aim of the preoperative phase is to evaluate the patient, to prepare him to surgery, and to give informations about the postoperative program.

Evaluation should comprehend the elbow joint and all correlate articulations, being performed in both analytical and global paths to highlight possible wrong postural attitudes which could be correlated to the articular pathology.

To perform a good joint evaluation is necessary to use validated scores that allow to monitor the clinical evolution and the treatment effectiveness, to compare the results obtained by different prostheses models, and to facilitate the data exchange in the scientific environment.

The investigated fields in elbow evaluation scores are ROM, pain, and the ability to ADL performing. Because no evaluation scores are indicated to assess all pathologies that could involve the elbow, we can use many useful scores. The Mayo Elbow Performance Score (MEPS), the Hospital for Special Surgery Score (HSS), and the Score of the European Society of Shoulder and Elbow Surgery (SECEC) are the most indicated in cases of prosthetic replacement (Dowrick et al. 2005; MacDermid 2001; Sathyamoorthy et al. 2004; Turchin et al. 1998).

MEPS is an easily administered score, which requires a short-term training; it does assess neither strength nor joint deformity, and ROM is measured only in terms of flexion-extension. Pain represents the highest percentage of the score: 45%; function is carefully assessed in terms of capacity to execute the daily life tasks: this parameter then represents a substitute of the first three (Morrey 2002).

HSS is a 100-point score on which the pain accounts for 30%. It assesses elbow function in general terms and as time spent to perform specific activities. ROM is assessed in both flexion-extension and pronation-supination. Patient ability to flex the elbow from 0 to 30° using different weights is the method for strength evaluation.

SECEC score is another 100-point score; it is more complete and thus more complex than the previous. The pain is the 35% of the score and is assessed both as the most intense pain of the last 24 h and as the percentage rate of interference during sleep, work, recreational activity, and the movement of the upper limb. ROM is intended as the higher pain-free active movement and is evaluated in both flexion-extension and pronation-supination; it accounts for 40% of the score. To evaluate the strength, a dynamometer is used, granting one point to each Kg lifted for a maximum of ten points in extension and 15 in flexion.

The main aim of the preoperative treatment is to reduce pain with physical therapy and eventually with drugs and to maintain ROM with active-assisted exercises. If we can obtain pain relief before surgery, also the postoperative management will be easier; chronical pain in fact causes a prolonged pathologic sensitization of nociceptors. This can induce a change in the central processing of the sensitive afferents and consequently causes a spinal and/or supraspinal hyperexcitability which in turn leads to C-fiber degeneration and the dorsal horn of spinal cord to an anatomical reorganization. Thereby, the different mechanisms of neuropathic pain may overlap one another over time, becoming pain chronic and self-maintaining. For this reason pain resolution is often the main goal of rehabilitation as well as the reason for the patients to undergo surgery. It is important to distinguish between central and peripheral pain; the evaluation of pain caused by pressure and the gripping painful strength measurement with dynamometer is useful on this purpose. For pain pressure is meant the pain evoked by the pressure on capsular and ligamentous trigger points. When pressure pain is predominant compared to the painful gripping one, this indicates the central genesis of pain, and a rehabilitative treatment that involves the cervical spine too is required. Conversely, when the painful gripping prevails, symptoms have a peripheral genesis and manual therapy is indicated.

This classification treatment based on the pain typology is founded on the more recent clinical experiences and has to be validated; however, it emphasizes the need to use appropriate instrument to guide the rehabilitation program (Gibson 2012).

Another goal of this phase is to improve the patient compliance informing him about the surgery and the following prolonged rehabilitation program.

19.1.3 Early Postoperative Phase

Aims of this phase are to solve edema and pain and to recover ROM. If pain and edema are not handled since the immediate post-surgery, rehabilitation time could be prolonged and the final result could be worse.

Edema and pain treatment is based on a series of measures summarized in the acronym PRICEMM (Morrey 2002): protection, relative rest, ice, compression, elevation, medicine, and physical and rehabilitative tools.

In the immediate postoperative patient wears an elbow splint at 90° of flexion with the upper limb in an unloaded position (Fusaro et al. 2014). To control pain, a peripheral block achieved with a perinervous catheter is proved to be useful. On the other hand, the use of a peripheral block requires an extra caution rehabilitation, due to the patient sensibility and thermic pain reduction. Ice is applied 2–3 times per day for about 15 min, avoiding the direct contact to the skin. In the first day, patient starts a cautious auto-assisted passive mobilization of the elbow: 30–40° of flexion/extension are allowed.

At the drainage removal, usually in the second day, patient with an unlinked prosthesis is provided with a hinged tutor, which must be worn for the next 4–6 weeks, allowing motion in a safe ROM. In case of linked prosthesis, a plaster cast is used for 2 weeks, and the patient will remove it only to perform self-assisted exercises. The cast will be definitively abandoned after 2 weeks.

In this safe ROM set by the surgeon, an active-assisted flexion-extension and pronation-supination will be continued. Passive- or active-assisted mobilization exercises are done first with the therapist and then should be repeated by the patient many times during the day.

It's desirable to reach 100° of flexion in the first postoperative week and to improve 10° for each incoming week. However, if the triceps tendon is detached with bone plug during surgery and then reinserted with trans-osseous suture, it is appropriate to limit the passive flexion movement and active extension to reduce detachment risk.

Surgical techniques that preserve triceps tendon insertion allow a wider flexion in the immediate postoperative period and an early use of the contiguous joints (wrist and hand) in daily life activities (Szekeres and King 2006).

Exercises to gain flexion are done gravity assisted in a supine position with the support of the healthy limb, which drives the operated arm hand toward the nose (Wolf and Hotchkiss 2006) (Fig. 19.1) and toward the opposite shoulder as the ROM increases. Studies show that there's a high rise of biceps muscle electromyographic activity in the post-surgical elbow in respect to the normal ones while triceps muscle activity is reduced (Page et al. 2003). For this reason the better position to mobilize in flexion a prosthetic elbow is with the patient supine or seated with the arm elevated because the movement occurs in favor of gravity without further increasing the biceps muscle recruitment.



Fig. 19.1 Active-assisted (gravity assisted) flexion

Even if the strength of triceps reinsertion could allow for an active extension even in the first days after surgery, we prefer to start extension recovery with a gravity-assisted exercise: the patient is seated relaxing the biceps muscle leaving the arm progressively to extend.

The pronation-supination recovery at this first period is different according to the type of implanted prosthesis. In case of unlinked prosthesis implant, pronation-supination must be performed with the elbow flexed not to excessively stress the reconstructed collateral ligaments. Conversely, when a linked prosthesis is used, pronation-supination can be performed also in extension. Moreover, to obtain the best pronation-supination recovery, we have to consider onward not only the proximal radioulnar joint but even the distal radioulnar joint, the interosseous membrane, and the flexor-extensor muscles of the wrist and the fingers for their interaction in this movement plain. Pronation-supination

exercises are performed asking the patient to rotate the forearm so that the palmar face of the hand is versed upward and downward.

Together with the active-assisted mobilization of the elbow, we associate a continuous passive motion (CPM) device at the fourth post-surgery day (O'Driscoll et al. 2002) in order to improve the ROM and to prevent and/or reduce the edema of the soft tissues with a "squeezing effect" during the flexion-extension movement (Fig. 19.2); CPM mobilization is done two times a day for 20 min each session for the greatest possible ROM and performed in slow motion, not to cause rebounded contractures; it can be facilitated in association to peripheral analgesia. In case of unlinked prosthesis, CPM use must be delayed waiting for the soft tissue healing because on the motorized device the elbow tends to lose its joint rotation center and could therefore undergo to varus-valgus stress damaging the repairing tissues.

To treat edema we always associate flexion-extension finger exercises for their useful effect on blood circulation and lymphatic drainage massage according to Vodder's technique. Recently, some authors have suggested a possible utility of the Kinesio Taping technique for this purpose (Fig. 19.3). Kinesio Taping method involves an elastic tape with specific characteristics that make it quite similar to the skin. Drainage of the edematous areas is obtained with the "lymphatic correction technique" that uses low tension of the tape (Williams et al. 2012). In our personal experience, we haven't used the taping yet for this purpose also because the people's skin often reflects the underlying pathology and age and is quite thin and easily macerates.



Fig. 19.2 Mobilization with motor device (CPM)



Fig. 19.3 Antiedema Kinesio Taping modality

Together with the analytical treatment of the elbow, we associate even the mobilization of the adjacent joint, the shoulder, and the wrist, because of their consequence on the elbow's function.

19.1.4 Late Postoperative Phase

The aims of this phase that start about 20–30 days after surgery are the recovery of a complete (or near complete) ROM, muscular strength, and upper limb function.

ROM recovery must take place both in flexion-extension and pronation-supination planes. Because the "elbow's system" has very complex neurophysiological characteristics, ROM recovery must be performed as described before as well as by the cognitive therapeutical exercise. In the beginning these exercises are performed without muscular recruitment: the patient must be able to recognize the paths, angular grades, or pressure stimuli suggested by the therapist (Figs. 19.4 and 19.5). Only when the perceptive function is recovered, the exercises are performed with similar tools but with the muscular recruitment.

Muscle recruitment allows recovering a proper range of movement that integrates both the components: top-down (the own factors of the central nervous system that oversee the organization of adaptive functions) and bottom-up (the own elements of the locomotors system, that govern and oversee the adaptive function expression and of which the central nervous system must be taken into account to organize the function itself). ROM recovery may also require the use of mobilization techniques and active exercises.

Finally, to increase ROM recovery, stretching exercises can be used after about 6 weeks from surgery. These exercises



Fig. 19.4 Perceptive exercise with tracks execution



Fig. 19.5 Exercise for pronation-supination recovery by recognition of movement angles

can be done assuming specific postures (Fig. 19.6) or with elastic bands, holding them at non-painful limit in matter not to stimulate the stretch muscular reflex.

Stretching exercises are performed in flexion, extension, and pronation-supination: elongation is maintained for 10–15 s to the maximum stretch tolerated by the patient to allow the retracted soft tissues to length; it should be repeated ten times a day. Stretching extension exercises using weights upon forearm are avoided because this may increase the biceps muscle hyperactivity. We always associate a scar massage using the friction and the pinch roller techniques. During rehabilitation there may be a stop in ROM recovery with a flexion stiffness due to the ulnar nerve irritation by the post-surgical fibrosis (Szekeres and King 2006); this is associated with pain in ulnar nerve territory, occasional paresthesia, and a positive Tinel sign. In cases of no conservative resolution of this scenario, a surgical neurolysis may be needed.

To bypass this problem, surgeons we work with are used to routinely perform a subcutaneous ulnar nerve anteposition at the end of surgery, thus making this complication extremely rare.

Muscular strength and resistance recovery starts at the 10th week and only if the elbow has achieved a wide enough ROM of about 70–80° (Morrey 2002).

Extremely important is an efficient recovery of the extensor muscle component; triceps strengthening indeed, in addition to its functional value, plays a decisive role as joint stabilizer maintaining a correct humeral-ulnar axis by centering the olecranon-trochlear joint. Contraction of anconeus muscle is associated to triceps. Anconeus muscle has slow fibers which are activated by low loads and slow movements (Zhang and Nuber 2000). It has an important role as varus stress joint stabilizer. The patient gains consciousness of this muscle while palpating it during an extension isometric contraction of the forearm against resistance. Then patient learns to maintain the muscle contraction during the whole ROM, both in extension and pronation-supination.

To gain muscle strength, therapeutical exercises are indicated using tools opposing resistance to mobilization and then determining a wider number of motor unit recruitment (De Giovannini 2000) (Fig. 19.7). Active flexion-extension movements are also performed in a gravity-assisted manner for the first 4 weeks after surgery. At the sixth week, the patient can perform extension of the elbow with the limb over the head in a seated position. Manual opposed exercises in the different movement planes are performed around the 9th–10th postoperative week, initially in an analytical modality,



Fig. 19.6 Flexion stretching



Fig. 19.7 Perceptive reinforcement exercise: tool improves the friction and thus the muscular recruitment

and then according to the proprioceptive neuromuscular facilitation method (PNF), with an accommodating contrast and diagonal directions.

The use of weights (Morrey 2002) is done with low loads to avoid excessive compressive forces across the prosthetic implant and to allow an alternating concentric-eccentric contraction of the flexor-extensor muscles but also an isotonic contraction because of the constant weight; resistance on flexor muscles is diminished by flexion and is improved by extension. Muscle contraction is still concentric-eccentric even with elastic bands, but flexor tension is improved as long as the flexion increases (Fig. 19.8). Speed acts modifying the exercise intensity: at higher velocity indeed, forces acting upon the joint are reduced (Morrey 2002).

In patients with unlinked prosthesis, active extension-supination movements have to be avoided during the muscular strengthening phase because they could induce a prosthesis subluxation.

If despite this work the upper limb muscles still remain hypotrophic, the high-voltage electrotherapy is indicated because it is not very painful and thus allows a wider muscular recruitment. Electrotherapy is performed on the flexor muscles and extensors ones sequentially to maintain balance of both compartments.

The third goal of rehabilitation is the whole upper limb function recovery. To obtain this, first of all we have to recover the elbow connected joints if needed, and this should be done already in the immediate postoperative period to avoid the onset of compensatory movements and/or articular stiffness. The shoulder is the elbow platform, and it hasn't to be stressed in resisted external/internal rotation; the wrist often presents a flexion-extension deficit correlated to a radiohumeral dynamic affection.

In addition to the therapeutic exercises that promote the interaction of the upper limb with the external world, the proprioceptive reeducation is very useful in this phase for the recovery of the faster response to external solicitations. To provide the best proprioceptive exercises, it is important to remind that elbow ligaments and capsule are sectioned in the linked prosthesis; meanwhile, the collateral ligaments are reconstructed in the unlinked ones, and their function is fundamental for prosthesis stability. Therefore, perceptive and proprioceptive stabilizing exercises have greater sense of being proposed if the patient has an unlinked prosthetic



Fig. 19.8 Concentric-eccentric reinforcement for flexor and extensor muscles

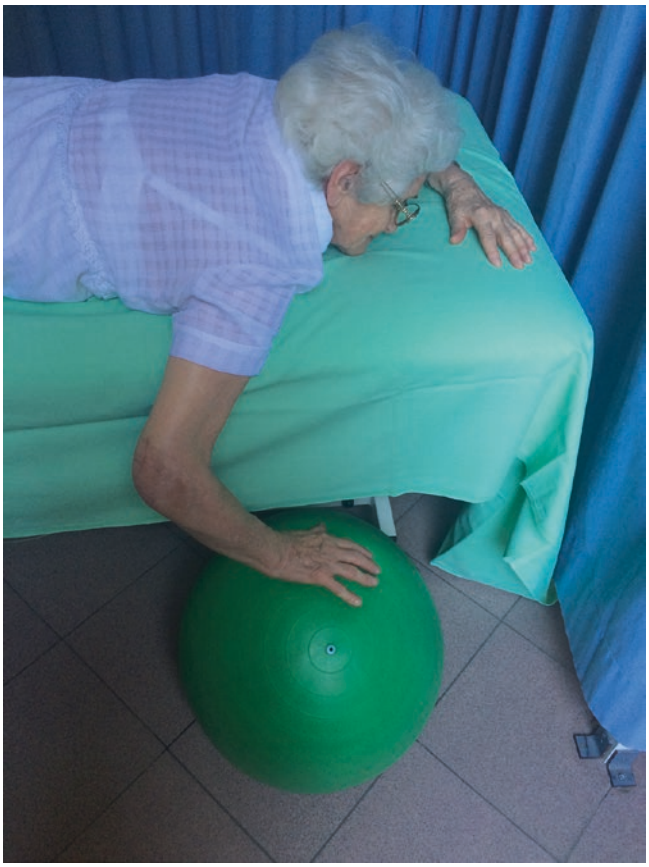


Fig. 19.9 Proprioceptive CKC exercise

implant. Proprioceptive rehabilitation starts when the elbow reaches a wide and not painful motion. Exercises are done in traction, suspension, and compression using either closed or open kinetic chain (CKC and OKC); difficulty of the exercises increases progressively as well as tool instability (Figs. 19.9 and 19.10).

Perceptive and proprioceptive work is completed with postural realignment, performed according to global techniques and associated to respiratory control.

Finally, since the immediate postoperative time, the core muscle strength and a corrected activation timing must be maintained (oblique, transversus, and rectus abdominis) using neurocoordination exercises which involve the whole kinetic chain (Di Giacomo and Ben 2005).

Hydrotherapy requires the presence of qualified staff and can be successfully used to achieve the treatment aims (Bender et al. 1993). In fact, water therapist can assist the patient with passive mobilizations of the elbow, at the same time avoiding any compensatory movement onset in the joints upstream and downstream of the elbow. To gain ROM and to perform symmetric stretching, cane exercises are very useful: the healthy limb is used to facilitate the movement of the operated one in all plans of the space. Glove and paddle exercises are responsible of a contrasted work inducing a variable and accommodating resistance by water and allowing an alternating activation of the agonist and antagonist muscles of the limb. With tables or tubes, it is possible to carry out proprioceptive exercises.

Rehabilitative treatment ends with the patient transition from the rehabilitation gym to an adapted physical activity or to the sports therapy. In fact these activities improve muscular strength, coordination, balance, and respiratory capacity. Moreover, the teamwork encourages integration, enhances self-identity, improves the self-esteem, and stimulates the competitive spirit of the patient.

Specific and age-appropriate sports will be selected on the basis of the patient desires; among the recommended sports are yoga and oriental disciplines, gymnastics in water, and dance.

Finally, occupational therapy can be a great help to encourage the people's ability in the daily life activities, social integration, and personal satisfaction.



Fig. 19.10 Proprioceptive overhead CKC exercise

19.2 Authors Personal Experience and Opinion

As described up to here is what we usually do in our clinical practice with the support of literature and according to the surgeon with whom we interact constantly.

It's appropriate at this point to briefly mention the aspects of paramount importance for us and the necessary precautions for the best "maintenance" of the implanted prosthesis.

- First of all it must be clear to the patient that since the elbow prosthesis is implanted, he doesn't have to lift more than 2 kg weights. This is one of the main information that the surgeon usually gives the patient when this type of surgery is proposed, but it's also the duty of the rehabilitator to keep reminding and stressing this concept.
- In addition to the prohibition on lifting weights and then to perform heavy labor, it is necessary to teach the patient a limb "cautious" use even for the usual ADL to avoid all activities that may put the prosthesis at risk of loosening. Reimplantation of an elbow prosthesis is a demanding surgery: technically very complex and usually associated with very poor functional results.
- For this reason, we'll remember the patient to always report the fact that he has an elbow arthroplasty if he has to be subjected to other procedures requiring the subsequent use of crutches.
- From the above it is clear how we believe and insist on the necessity of a patient's annual medical control filled with new Rx elbow prosthesis even in case of well-being.
- We recommend to the patient also an appropriate antibiotic prophylaxis whenever he needs to undergo further surgery even minors (e.g., dental procedures) because unfortunately we have witnessed the onset of infection even in the long term after the implant when the danger seemed warded off. In this sense, proper patient education is very important.
- To be real, for us the concept of sport is actually very restricted: we recommend patients soft gym and never with weights nor with "quadruped" postures. Instead we prefer swimming or water gym but possibly avoiding tools if the instructor is not a therapist or is not aware of the problems related to the elbow prosthesis. About this, we remember that often those who need elbow arthroplasty are elderly patients already debilitated by other comorbidities or even patients of younger age but with a still fragile bone structure for concomitant rheumatic diseases.

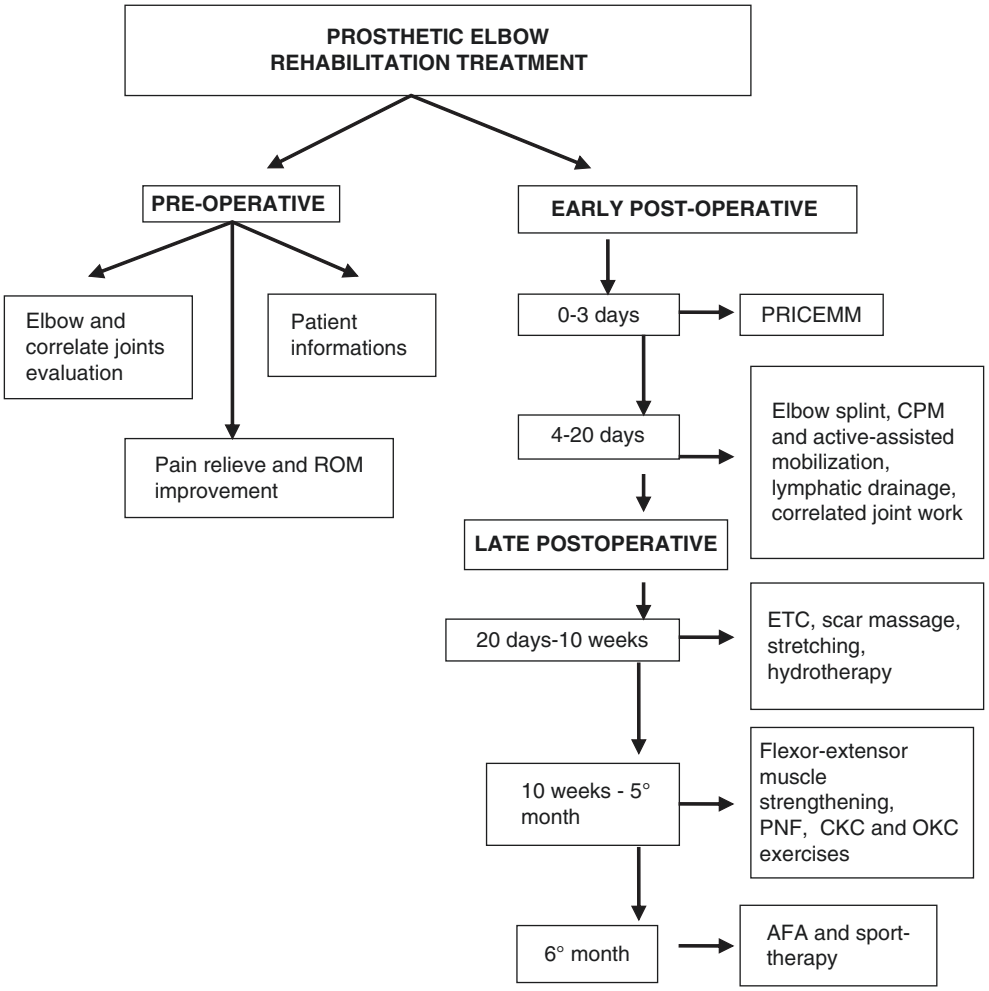
An interesting study supporting the need of our efforts to recommend patients not to perform any moderate- and high-demand activities after a total elbow arthroplasty is the one of Barlow et al. (2013).

The results of this study show that a great number of patients perform moderate- (94%) and high-demand (40%) activities after total elbow arthroplasty despite the surgeon's recommendations even if two thirds of patients were aware of what they were told actually.

Then, the truth is that despite our recommendations, the patient real behavior when he will return to his life we cannot really know!

Conclusion

In parallel with the prosthetic technology evolution, rehabilitative programs have been developed for the patients with elbow prosthesis to reach the better possible functional results. To develop this therapeutic program, in addition to surgeon indications, it is necessary that we rely on the knowledge of the elbow function that comes from biomechanics and neuroscience studies. Only in this way, the complex elbow joint can be adequately recovered, thus becoming no longer the "orphan joint" of the upper limb but the "key joint" of the finalized movements. Indeed, in literature there are few bibliographic references about rehabilitation after elbow prosthetic replacement. Rehabilitative treatment is mostly based on the knowl-



edge of the elbow physiopathology rather than evidence-based treatment strategies (Walker-Bone et al. 2004). As it regards patient prognosis, it's important to point this up: in contrast to other joints for which the prosthetic design is prime, for the elbow the prosthetic design has a close correlation to its pathology. For this reason, results will be different depending on prosthesis which is implanted because of arthrosis, rheumatoid arthritis, or distal humeral fractures and their sequelae.

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Paediatric Elbow Fractures and Rehabilitation

20

Diego Antonioli, Manuele Lampasi, Stefano Stilli, Isabella Fusaro, and Stefania Orsini

20.1 General Concepts

Upper-extremity fractures account for 65–75% of all fractures in children (fall on outstretched arm mechanism). The most common area injured is the distal forearm; 7–9% of upper-extremity fractures involve the elbow.

The distal humerus accounts for approximately 86% of fractures about the elbow region in children, and supracondylar fractures are the most frequent injuries, reported to occur in 60–80% of patients. Lateral condylar fractures are the second most common (17%), followed by medial epicondylar fractures. Fractures of the olecranon, radial head and neck and medial epicondyle and T-condylar fractures are much less frequent (Kasser and Beaty 2006a; Price and Flynn 2006).

Comparing with adult age, elbow dislocation is relatively uncommon (3–6% of all elbow injury).

Precisely defining the fracture patterns in young children is a challenge because of the large cartilage composition of the distal humerus. There are also multiple ossification centres that appear at different ages (Fig. 20.1) and represent critical landmarks for an accurate radiological evaluation.

The capitellum is the first to appear (6–12 months of age), followed by the radial head and the medial epicondyle at 5 years of age.

The trochlea ossifies at 7 years, and the lateral epicondyle and olecranon appear at 9 and 11 years of age, respectively. The lateral epicondyle, trochlea and capitellum coalesce to form a single epiphysis by 12 years of age. Ossification centres are intra-articular except for the medial and lateral epicondyles.

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Any swelling or restriction of movement requires detailed instrumental evaluation, sometimes with comparative radiography of the opposite elbow whenever there is doubt regarding normal anatomy. Ultrasonography and MRI must be considered a helpful option in young children in which cartilaginous parts of the skeleton cannot be visualized on standard radiography in the suspicion of occult and articular fractures (Kasser and Beaty 2006a; Price and Flynn 2006; Mubarak and Davis 2002; Gillingham and Hadden 1998).

20.2 Supracondylar Fractures of the Distal Humerus

The supracondylar humerus fractures are the second most common fracture in childhood after forearm fractures and represent the most common fracture involving the elbow (60–80%). The peak age is 5–8 years.

These fractures are almost always (in 96% of cases) due to accidental trauma, such as falling from a moderate height, on an outstretched hand with elbow and forearm hyperextended. More rarely, they are the result of a fall directly onto the olecranon or distal humerus with flexed elbow. Open fractures, generally with anterior exposure, occur in 1% of cases. The displacement of the distal fragment is postero-medial in 75% of cases, posterolateral in 25%.

Associated neurovascular complications are relatively frequent (reported from 5 to 19% in literature) (Kasser and Beaty 2006a; Price and Flynn 2006; Mubarak and Davis 2002; Gillingham and Hadden 1998). Therefore correct clinical management both in the acute phase and follow-up is essential. Although this is a "classic" chapter of paediatric traumatology, supracondylar fractures are still the focus of many discussions. Over 250 articles in

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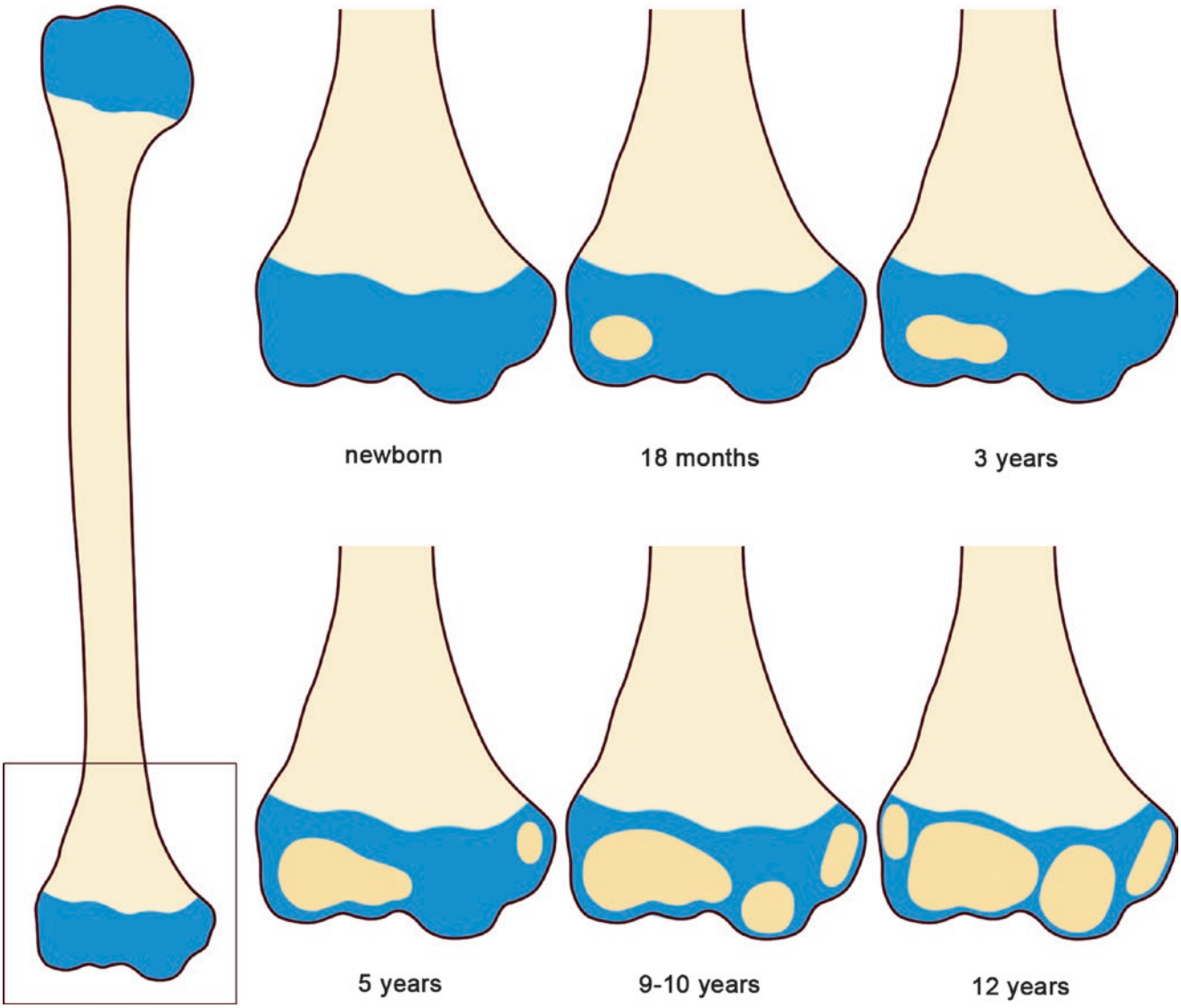


Fig. 20.1 Ossification centers of the distal humerus in child

peer-reviewed journals only in the last 5 years could emerge from an online search by typing term "Supracondylar-humerus fracture-children", and this confirms that complete guidelines, based on evidence, have still not been established.

20.2.1 Classification

Classification is based on the Wilkins system that is a modification of the Gartland system (Kasser and Beaty 2006a).

Type I: un-displaced fracture (Fig. 20.2).

Type II: Greenstik fracture with posterior angulation.

Type IIA: posterior angulation; there is no rotational displacement with intact posterior cortex (Fig. 20.3a).

Type IIB: posterior angulation with rotational displacement (posteromedial or posterolateral rotational displacement) (Fig. 20.3b).

Type III: completely displaced (Fig. 20.4).

Type IIIA: complete posteromedial displacement of distal fragment (more frequently presents involvement of the posterior interosseous nerve).

Type IIIB: complete posterolateral displacement of distal fragment (worse prognosis, involvement of brachial artery and median nerve).

Type IV: This type, not a part of Gartland's original classification, was added more recently by other authors and describes a complete periosteal disruption with instability in flexion and extension. These clinical-radiological findings could be also due to an overly aggressive reduction manoeuvre in flexion (Leitch et al. 2006).

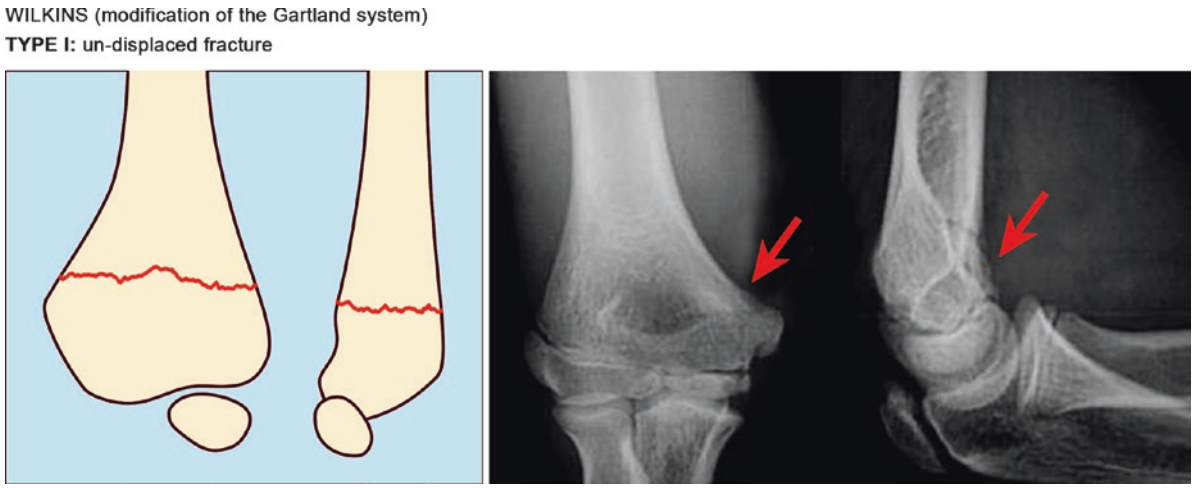


Fig. 20.2 Type 1 supracondylar fracture

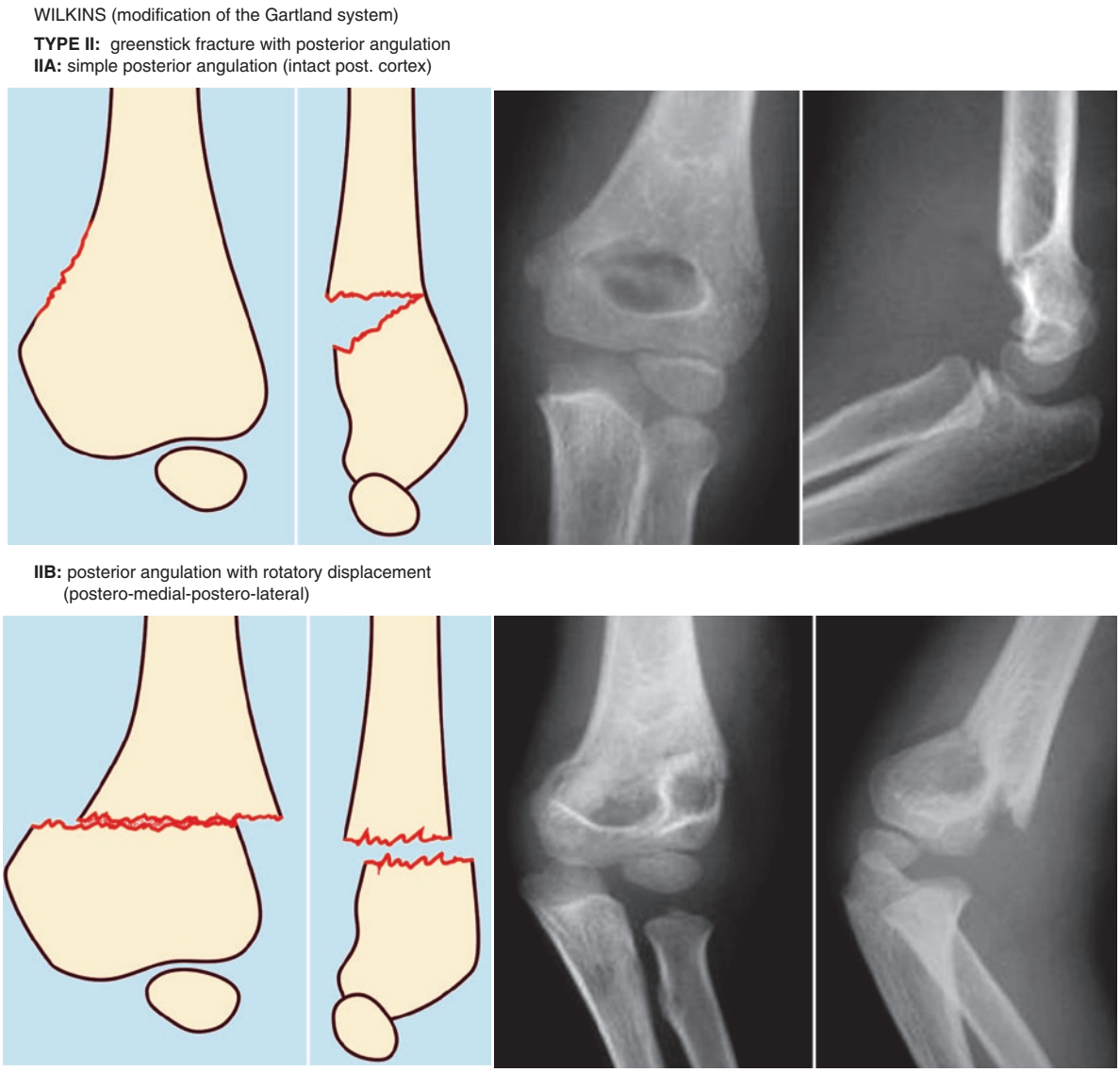


Fig. 20.3 Type 2A supracondylar fracture - Type 2B supracondylar fracture



Fig. 20.4 Type 3 supracondylar fracture

20.2.2 Presentation

In younger patients, it could be difficult to discriminate between analgesic deficiency of basic movements and paresis-paralysis due to neurological insult. For this reason a correct clinical assessment of the extension of the swelling and of the peripheral circulatory status (radial pulse, capillary refill, peripheral O_2 saturation), as well as a precise neurological objectivity, is essential in acute evaluation (Abzung and Herman 2012).

The olecranon traction could be used in the case of comminute fracture or very marked swelling. This treatment allows at least partial reduction of the fracture and resolution of the edema preventing muscular contracture and neurovascular complications (Volkmann Syndrome).

20.2.3 Imaging: AP View

Baumann's angle (Fig. 20.5) is formed by the perpendicular to the long axis of the humeral shaft and the physeal line of the lateral condyle. On a normal AP the normal angle is 70–75°. A decrease in Baumann's angle may indicate coronal plane deformity, varus angulation, internal rotation deformity of the distal fragment or medial comminution. A perfect anteroposterior view of the distal humerus, placed

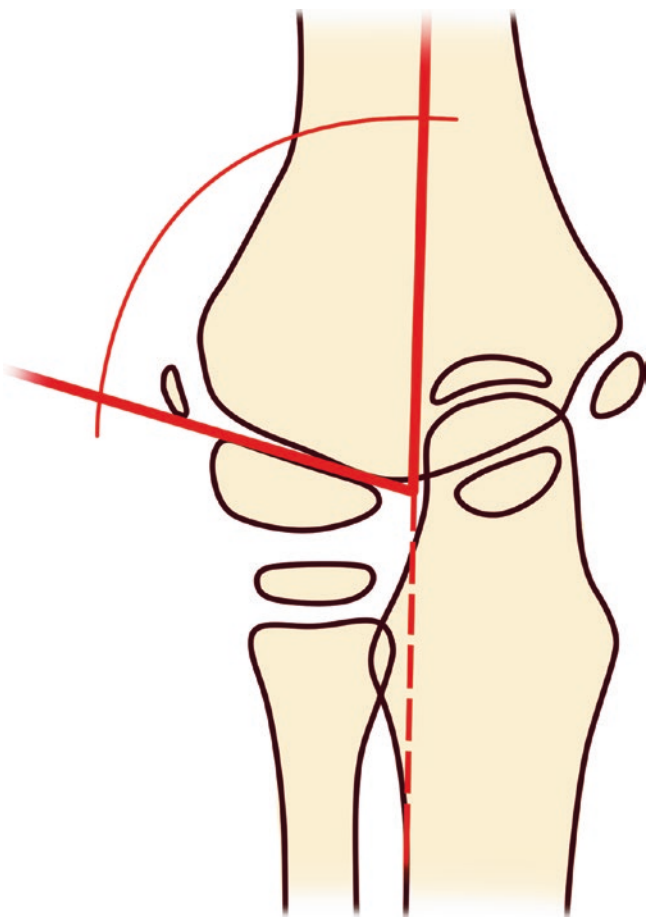


Fig. 20.5 Boumann's angle

parallel to the radiographic plate, is necessary to reduce the variation of the Baumann angle that occurs when the arm is rotated. Ten degrees of rotation produces a 6° change in the angle. A comparative AP of the contralateral side is recommended for an accurate evaluation.

20.2.4 Radiocapitellar Line (Fig. 20.6a, b)

A line drawn through the centre of the radial neck should pass through the centre of the capitellum, whatever the position of the patient. In supracondylar fractures this relationship is preserved while in elbow dislocation, displaced lateral condyle fracture and in Monteggia lesion is compromised.

20.2.5 Lateral View

Anterior humeral line (Fig. 20.7): a line drawn along the anterior surface of the humerus should pass through the middle third of the capitellum. In cases of a supracondylar fracture, the anterior humeral line usually passes through the anterior third or in front of the capitellum due to extension of humeral fragment.

Teardrop sign/hourglass sign (Fig. 20.8): interruption of the teardrop (generally anterior gap) in extension fractures.

Anterior coronoid line (Fig. 20.9): originates from the coronoid process of the proximal ulna and should pass through the anterior capitellum of the distal humerus. It should be smooth, continuous and concave.

Fat pad sign (Fig. 20.10): a visible fat pad sign without the demonstration of a fracture should be regarded as an occult fracture. In trauma displacement of the posterior fat pad is virtually pathognomonic of the presence of a fracture. Displacement of the anterior fat pad alone however can occur due to minimal joint effusion and is less specific for fracture.

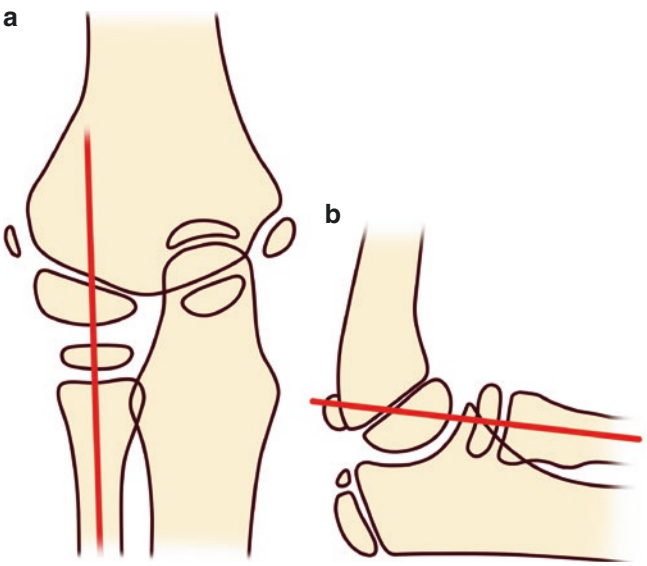


Fig. 20.6 Radio-capitellar line

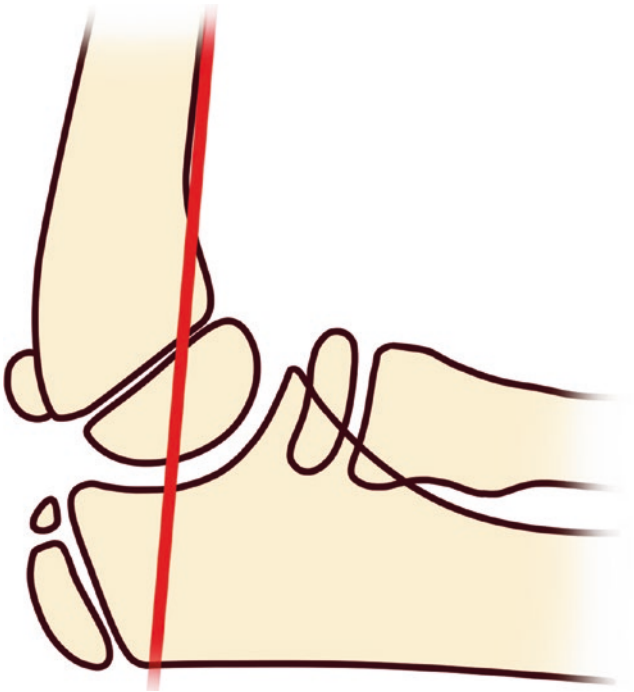


Fig. 20.7 Anterior humeral line

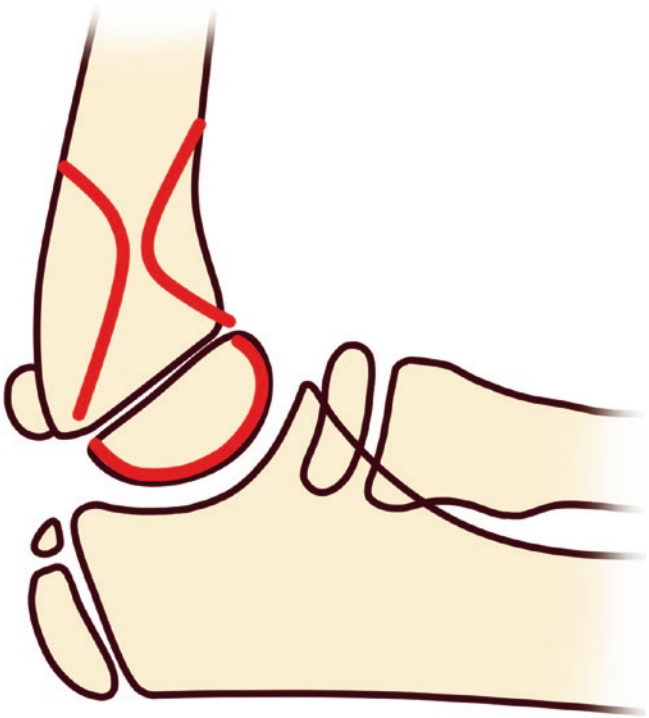


Fig. 20.8 Teardrop sign/Hour-glass sign

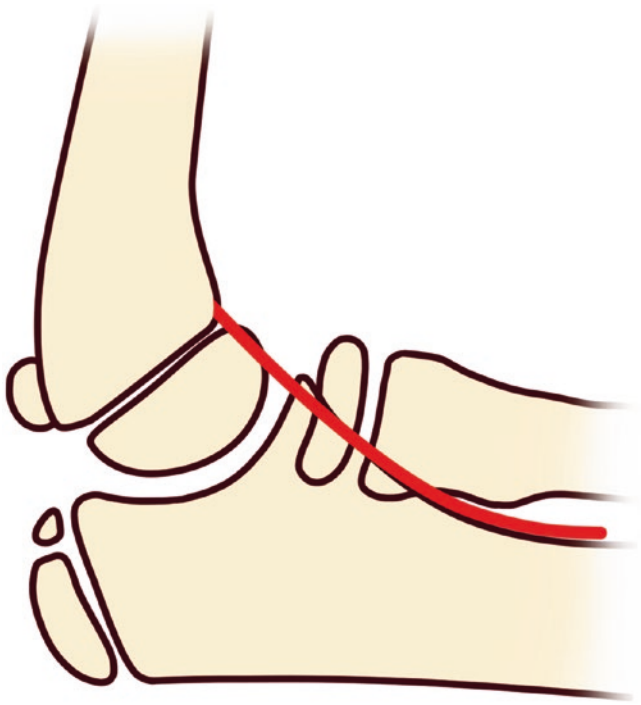


Fig. 20.9 Anterior coronoid line



Fig. 20.10 Fat pad sign

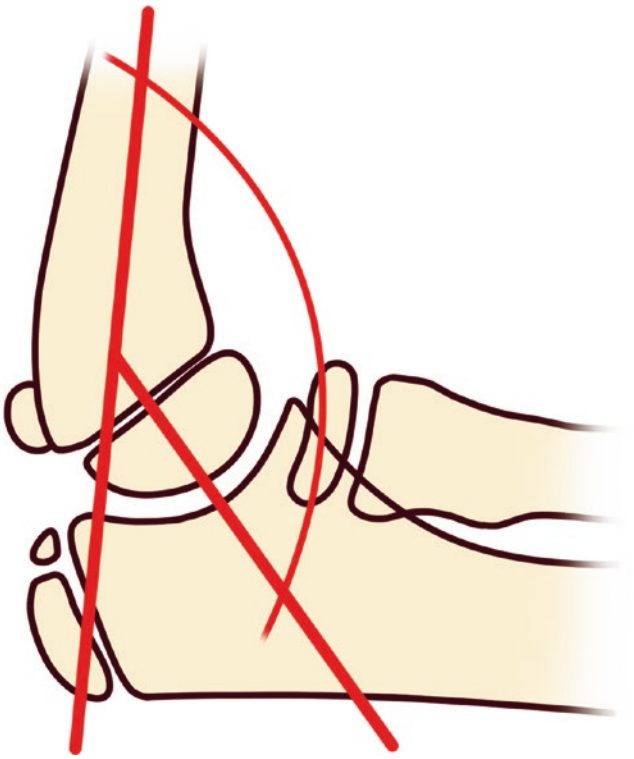


Fig. 20.11 Anterior angulation of the capitellum relative to the humeral shaft

Anterior angulation of the capitellum relative to the humeral shaft (Fig. 20.11): normal angulation is approximatively 150° (hockey-stick shape of the distal humerus). If this angle becomes wider, the fracture site is moved into extension (distal fragment in pulled posteriorly by the triceps muscle).

20.2.6 Timing of Treatment

Several recent publications (Iyengar et al. 1999; Mehlman et al. 2001; Gupta et al. 2004; Abbott et al. 2014; Bales et al. 2010; Kronner et al. 2013; Han et al. 2011) seem to indicate that the supracondylar fracture of the humerus in the absence of neurovascular complications at the presentation should be considered a deferrable urgency.

In particular, significant differences regarding the need for an open reduction, the incidence of iatrogenic neurological injury, the incidence of vascular complications and the quality of the final result (unsatisfactory reduction or insufficient results) do not appear when the fracture fixation treatment is delayed by 8–12 h.

As a result a planned surgery, executed by experienced personnel in the morning, is recommended even in the case of a night access to the emergency department.

Some authors report good results in the treatment of Type II fractures even after 48 h from presentation (Bales et al. 2010). Whereas the fractures in which at presentation the peripheral pulse is not palpable or peripheral neurological deficits are detectable require urgent treatment.

20.2.7 Treatment Algorithm

Type I fracture: conservative treatment.

Long arm posterior splint or long arm cast with 90° of elbow flexion, depending on edema.

Some authors suggest a bandage with flexed elbow (collar and cuffs) which seems to expose greater circulatory risks. Significant differences in various meta-analyses have not emerged between treatment with a simple splint or cast (Howard et al. 2012).

Type II fracture: closed reduction and percutaneous pinning—CRPP.

Some authors suggest a nonoperative treatment of *Type II* fractures with closed reduction if extension of the distal fragment exceeds 20° in particular to younger patients in which there is still good residual potential for remodelling in the sagittal plane (O'Hara et al. 2000).

An internal fixation is suggested in *Type IIA* fractures in older patients to avoid progressive displacement in extension, resulting in flexion stiffness.

CRPP is the gold standard in *Type IIB* fractures and in *Type III fractures*, which are displaced and associated with worst soft tissue injuries (wider periosteal laceration, brachial muscle penetration, neurovascular damage) (Abzung and Herman 2012; Howard et al. 2012; O'Hara et al. 2000).

Open reduction and internal fixation are indicated in the case of open fractures, peripheral ischaemia or vascular impairment after a reductive manoeuvre (post-reductive incarceration of the artery at the level of the fracture) and irreducible fracture (for delayed presentation, soft tissue interposition, extensive edema).

Some authors suggest that a marked posterolateral displacement, with medial spike close to the skin, greatly increases the difficulty in closed reduction. Precisely, an acute <45° "medial corner" (angle created by a line drawn through the medial cortex of the proximal fragment and the oblique fracture line) and a reduced fracture tip-skin distance (sign of a marked displacement) could suggest a greater difficulty in closed reduction (Fig. 20.12a, b) (Lim et al. 2013).

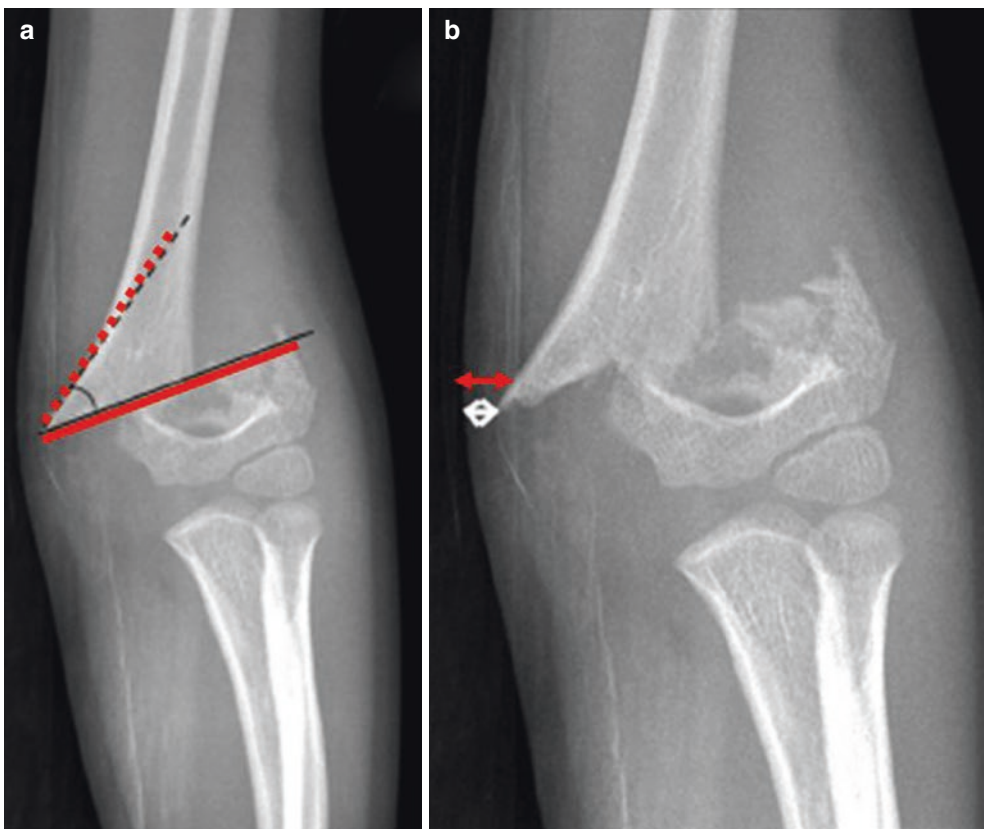


Fig. 20.12 Medial corner angle and fracture tip-skin distance

20.2.8 Remodelling Potential

The most active physes in the upper limbs are located in the extremities (proximal humerus, distal radius). The growth of the distal humeral physis is relatively low (about 20% of the length development of the humerus). This results into relatively low bone remodelling potential compared to other segments.

In particular, while a translation defect can remodel positively, a sagittal angulation remodels only partially and a coronal angulation and rotational defects minimally.

A physeal lesion at the time of the trauma, potentially present also in minimally displaced fractures, is possible and is difficult to assess even with a CT or RM evaluation. Biological damage in growing structures may result in cubital deformities, which tend to worsen with growth and can affect the outcome of any corrective operation performed before full skeletal maturity.

An adequate communication of this specific issue to the parent at the time of the fracture treatment remains essential, from a legal point of view, although the incidence of this complication was probably overestimated in the past.

20.2.9 Surgical Technique

Percutaneous pinning can be performed both in the supine position and in the prone position.

At our institute, percutaneous pinning is generally performed with the patient in the supine position, to simplify the management of the limb should there be the need for an open reduction. The patient's arm can be positioned on a radiolucent support or directly on the amplifier receiver.

The reduction is performed by traction to correct the frontal varus-valgus deviation and gradual flexion, pushing posteriorly on the olecranon, to correct the extension defect.

If the reduction is carried out correctly, a wide elbow flexion is possible; if this is not the case, it is advisable to avoid forcing the flexion and repeat the reductive manoeuvre from the beginning.

Closed reduction can be confirmed under fluoroscopy on AP (recovery of the metaphyseal shape and of the Baumann angle) and lateral view (recovery of the anterior humeral line and anterior angulation of the capitellum) X-rays.

The lateral column is stabilized with a first K-wire (usually K-wire of 1.6–1.8 mm in patients <20 kg—K-wire 1.8–2.0 mm in patients > 20 kg). The K-wire can cross the nucleus of the lateral condyle and the olecranon fossa without biological impairments.

A second lateral K-wire is advisable in more unstable fractures; two K-wires should be divergent in coronal and sagittal planes. In this way the elbow can be extended gently, and another K-wire can be positioned to the medial side. The risk of iatrogenic nerve injury from a medial pin must be considered, especially in younger patients where there is a higher incidence of physiologic anterior subluxation of the nerve during elbow flexion (about 18% in children <5 years). This risk is reduced if fixation is realized with elbow in semi-extension. Some authors suggest a mini-open medial approach in order to perform safe pinning, without need of nerve isolation; other authors suggest using three lateral pins (Mubarak and Davis 2002).

Crossed pins were biomechanically stronger to torsional stress, in tests performed on cadavers (Zionts et al. 1994). However, several meta-analyses conducted on large case studies and prospective randomized studies reported that fixation with lateral pins was biomechanically effective (poor results in 5.9% with lateral pins 3.4% with crossed pins) with a lower risk of iatrogenic nerve injury (0.7% vs. 3.4%) in clinical practice (Howard et al. 2012; Skaggs et al. 2001; Brauer et al. 2007).

During percutaneous pinning, three key elements need to be executed in order to obtain good stability and good reductions maintained over time: (a) the wires must penetrate the two cortices, avoiding that the K-wire slides within the medullary canal; (b) secure anchoring of both the fracture fragments, avoiding that K-wire comes out at the level of the fracture; and (c) proper "spacing" of the wires that must be divergent to not act mechanical stress as a single wire (Sankar et al. 2007).

The percutaneous wires are bended at a adequate distance in order to absorb additional postoperative swelling; a long arm posterior splint is applied, which can be replaced by long arm cast, once peripheral complications during the observation period have been excluded.

Immobilization is maintained for 3–4 weeks, the pins are then removed, and after radiographic evaluation, gentle mobilization is started.

20.2.10 Open Reduction

Open reduction is required in open fractures, neurovascular injuries, late treatment or inadequate reduction (2–15% of cases) due to interposition of the brachialis muscle or periosteum at fracture site. Anterior approaches (anterior, anteromedial, anterolateral) that allow direct exploration of the anatomical structures involved at fracture site preserving the posterior periosteal hinge are described in literature. These approaches, however, are more complex and unsafe, due to the contiguity of the neurovascular structures. A lateral approach (develops the plane between brachioradialis/extenders and triceps muscles) allows direct access to the entire anterior surface of the fragments and anatomical reduction of the fracture ensuring protection for the posterior soft tissues (possible difficulties in the reduction of the median column in case of comminution).

Posterior approaches allow a wide and relatively safe exposure of the distal fragment with good control of the rotary defect. However these approaches often generate surgical and biological injury of triceps and of the posterior periosteum, require isolation of the ulnar nerve and are related to greater postoperative stiffness, especially in the early weeks after cast removal.

20.3 Closed Reduction vs. Open Reduction

The advantages of open reduction are evacuation of fracture haematoma, a more anatomical reduction, direct visualization of potential interposed structures, the possibility to explore neurovascular structures and lower exposure to radiation.

The disadvantages are a greater risk of infection, the presence of unsightly scars, more severe postoperative stiffness and pain, longer consolidation time, longer overall surgical time and higher risk of avascular necrosis of the lateral condyle and of the trochlea, especially if the dissection on the lateral column is conducted too distally on the posterior side (Mulpuri and Wilkins 2012). These disadvantages lead us to consider open reduction as a second choice.

20.3.1 Complications

20.3.1.1 Primitive Neurological Injury

The incidence of neurological injuries in paediatric supracondylar fractures was probably underestimated in the past. A wide meta-analysis, recently conducted using appropriate selection criteria, reported that over 11% of extension-type supracondylar fractures presented neurological injury at diagnosis. The anterior interosseous nerve, which innervates flexor pollicis longus and flexor digitorum profundus, is the most frequently affected (34% of cases) and involved in case of posterolateral displacement of distal fragment.

The posterior interosseous nerve, a branch of the radial nerve, is the second most frequently affected, especially in case of postero-medial displacement (inability to extend wrist or fingers).

The ulnar nerve is by far the most frequently affected in flexion-type supracondylar fractures (91% of cases) (Babal et al. 2010).

Primitive neurological injury can occur with mechanism of trapping, stretching, tearing/interruption due to proximal fragment displacement or to marked post-traumatic oedema/swelling.

Anatomical studies have shown that the anterior interosseous nerve could be damaged through three different mechanisms: (a) direct injury from proximity with an anterior bone spike of the proximal fragment; (b) the arch created by the pronator teres holds the nerve, during the posterior displacement of the distal fragment; and (c) the interosseous membrane contiguous with the interosseous portion of the nerve is a point of fixture which further aggravates the distraction of the proximal fibres (Vincelet et al. 2013). In most cases, primitive neurological injury is a transient neurapraxia, with recovery time between 4 and 16 weeks; neurapraxia is slightly more protracted when the median nerve is involved. There is no agreement on the indication for surgical exploration of the nerve injury. Surgical exploration is considered in the case of acute post-reductive deficit (nerve injury not present before fracture reduction, due to trapped nerve) and, according to some authors, when the nerve has not recovered in the EMG evaluation 4 months after trauma (Gosens and Bongers 2003).

20.3.1.2 Secondary Neurological Injury

Secondary neurological injury can occur in the case of reductive manoeuvres (stretching—entrapment), direct or indirect injury by percutaneous pinning (direct drilling, stretching of the nerve, reduction of the cubital tunnel due to excessive scarring) and progressive axial deviation (cubitus varus, cubitus valgus). The ulnar nerve is the most frequently involved.

In ulnar nerve injury following CRPP, there is no scientific evidence of a better clinical evolution in cases of nerve exploration, neurolysis or early removal of the medial pin. Commonly recovery is spontaneous and complete in 4–6 months (Gosens and Bongers 2003; Skaggs et al. 2001; Brauer et al. 2007; Kalenderer et al. 2008).

20.3.2 Vascular Injury

As many as 10% of patients with displaced supracondylar humeral fractures may present with an absent pulse (Choi et al. 2010). Vascular injury can occur with mechanisms of trapping, stretching, tearing/interruption and compression at fracture site.

The need for acute vascular exploration remains a highly debated and very current topic, also due to the potential involvement of a vascular surgeon in the emergency department (Abzung and Herman 2012; Howard et al. 2012; White et al. 2010).

The following algorithm appears to be acceptable, according to the recent revisions conducted by the North American Society of Paediatric Orthopaedics and Traumatology:

- Open fracture with vascular insufficiency: open reduction and fixation
- Closed displacement fracture with vascular insufficiency: CRPP checking vascular status after reduction; adequate clinical observation if there is evidence of good distal perfusion; and immediate vascular exploration if there is evidence of poor distal perfusion
- Pink Pulseless Hand—PPH: observation if good Doppler pulse, 99% of O_2 saturation, good capillary refill (Choi et al. 2010; Benedetti Valentini et al. 2013); consider vascular exploration if Doppler pulse unclear, irregular saturation, unsatisfactory capillary refill and associated neurological deficits (Mangat et al. 2009)

Vascular counselling is recommended when the instrumental data (oximetry, Doppler pulses, displacement with acute proximal spike on the X-rays) and clinical data (degree of displacement and features of fracture fragments, capillary refill, associated neurological deficits, marked soft tissue involvement) are uncertain, despite recording a level of inconclusive evidence in the literature regarding the need for vascular exploration in PPH.

20.3.3 Angular Deformity

Mal-union is the most frequent complication after treatment of paediatric supracondylar fractures, while non-union is rare. A precise interpretation of X-rays, correct reduction and stable fixation generally provide a good evolution, while an insufficient reduction in the coronal and axial plane, a technically incorrect/insufficient fixation and an overestimation of the elbow remodelling potential may cause macroscopic angular/rotational deformities.

The most frequent mal-union deformity is the cubitus varus, resulting from a tilt in the coronal plane (Fig. 20.13). This is usually only a cosmetic problem when varus deviation is less than 10°. However, difficulty in performing overhead sports (volleyball, tennis, swimming) and daily activities such as dressing, bathing and lifting weights (such as school bags) with more severe compensatory



Fig. 20.13 Clinical examples of post-traumatic cubitus varus

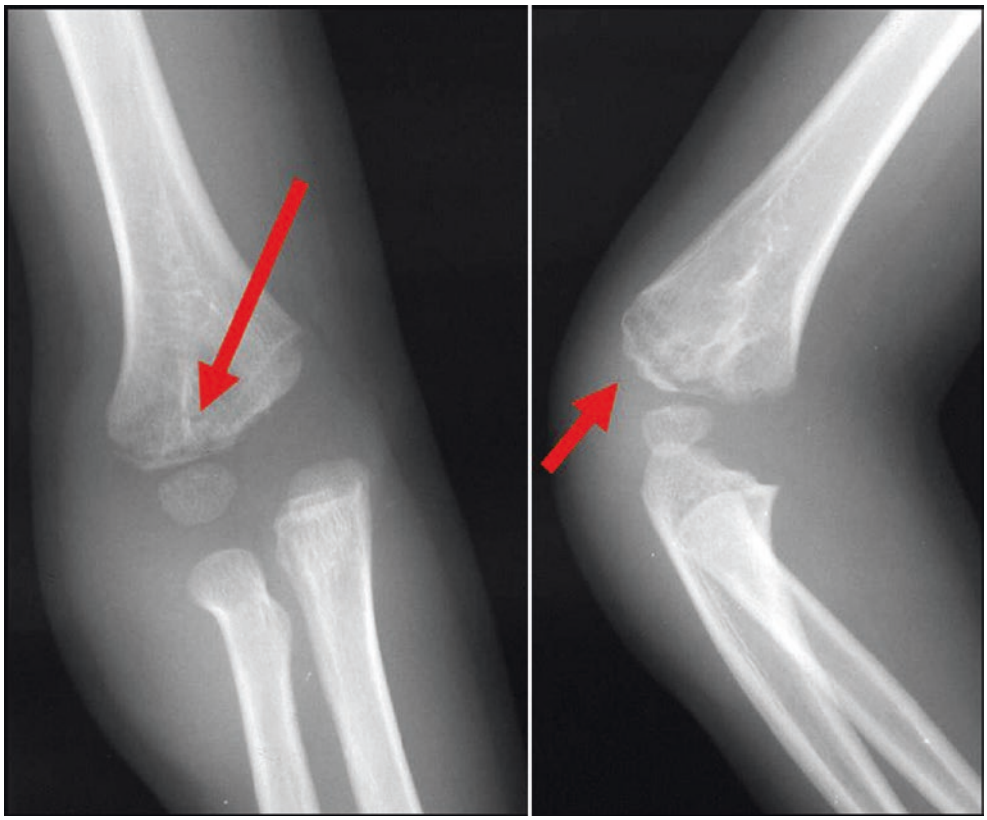


Fig. 20.14 Lateral condylar fracture of the humerus following post-traumatic cubitus varus

mechanisms is reported when varus deviation is higher. Moreover, the deviation exposes the lateral condylar region to increased traumatic risk during falls because the absorption capacity of mechanical stress with the elbow extended has been compromised, amplifying distraction forces on the lateral compartment (Fig. 20.14) (Davids et al. 1994).

Late ulnar nerve neuropathies because of instability/subluxation are described in case of mal-union with varus deviation more than 20° (Jeon et al. 2006). An increased risk of posterolateral instability of the elbow (also 20 years after trauma) due to the medialization of the triceps-olecranon force vector is also described (O'Driscoll et al. 2001).

20.3.4 Stiffness

Stiffness is also reported as possible complication, due to mal-union in extension (elbow hyperextension), rotational defect or protracted postoperative immobilization. Sometimes after open reduction, the scar tissue, the increased pain and the apprehension of patients may further delay the recovery of the ROM. In these cases, some authors suggest gentle-assisted physiotherapy (see physical therapy chapter) (Keppler et al. 2005).

A rare but dreaded complication is post-traumatic *myositis ossificans*, which can involve the brachialis muscle with widespread anterior ossifications (Fig. 20.15a–c). Forced mobilization of the operated elbow is not recommended to prevent this complication; suspension of mobilization and a Doppler ultrasound study are suggested if the elbow presents swelling, rubor and a severe painful ROM a few weeks after surgery. The complete maturation of ossification occurs typically in 5–6 months. A bone scan may be useful for diagnosis.

Treatment is generally conservative (spontaneous reabsorption is described in 30% of cases). Surgical solutions should be carefully considered, and results can be unpredictable. Pharmacological adjuvant protocols in childhood are not described in the literature (Kasser and Beaty 2006a; Gindele et al. 2000).

20.3.5 Lateral Condyle Fracture

Lateral condyle fractures of the humerus in childhood can be challenging in both diagnosis and management. Poor results with severe and debilitating outcomes may often require complex salvage surgery. Therefore a precise instrumental interpretation of the features of the fracture such as extension and stability is essential.



Fig. 20.15 3D reconstruction (**a**) of anterior post-traumatic ossification (myositis ossificans), postop X-ray (**b**) (elbow arthrolysis) and the clinical result (**c**) at the follow-up

Fractures of the lateral condyle represent 16–20% of the distal humerus fractures. The peak age of incidence is 5–7 years old. These occur either after traction mechanism in varus stress (due to extensor carpi radialis longus and brevis and lateral collateral ligament) or after a fall onto outstretched hand producing an impact of the radial head on the lateral column. The first mechanism is more frequent and could generate a fracture line directed towards the trochlear apex, due to stabilization created by the articular surface of the olecranon; the second one could be responsible for the rarest transcondylar fracture (Milch Type 1) (Kasser and Beaty 2006b).

20.3.6 Classification

Multiple classification systems that assess extension and features of fracture lines, degree and severity of the displacement and joint stability are described in literature.

Milch: *direction of fracture line* (Fig. 20.16) (Milch 1964)

- Type 1: rare (5%).
- Type 2: it involves the trochlea (increased instability).

Jakob: *radiocapitellar alignment* (Fig. 20.17) (Jakob et al. 1975)

- Type 1: incomplete fracture, articular surface intact
- Type 2: complete fracture, interruption of articular surface (humeral-radial alignment preserved)
- Type 3: complete fracture, loss of the humeral-radial alignment

Rutherford: *displacement severity* (Rutherford 1985)

- Stage 1: un-displaced fracture with cartilaginous hinge and articular surface intact
- Stage 2: interruption of cartilaginous hinge with minimal/intermediate rotational displacement
- Stage 3: severe displacement

Finnbogason: *displacement risk* (Fig. 20.18) (Finnbogason et al. 1995)

- A: fracture line does not reach the epiphyseal cartilage.
- B: fracture line clearly exits through the epiphyseal cartilage (possible displacement).

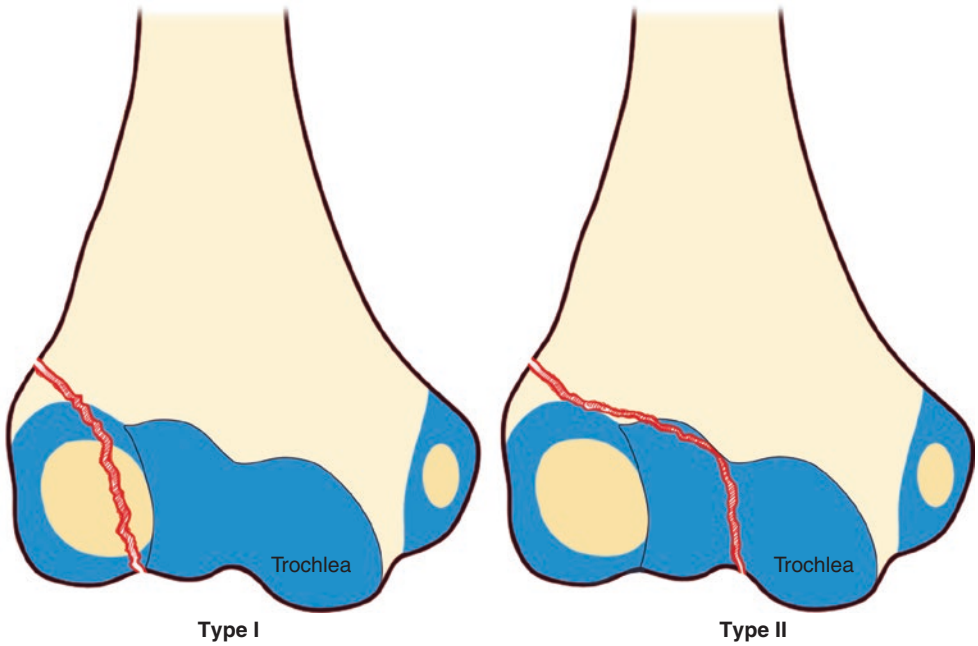


Fig. 20.16 Lateral condyle fracture: Milch classification

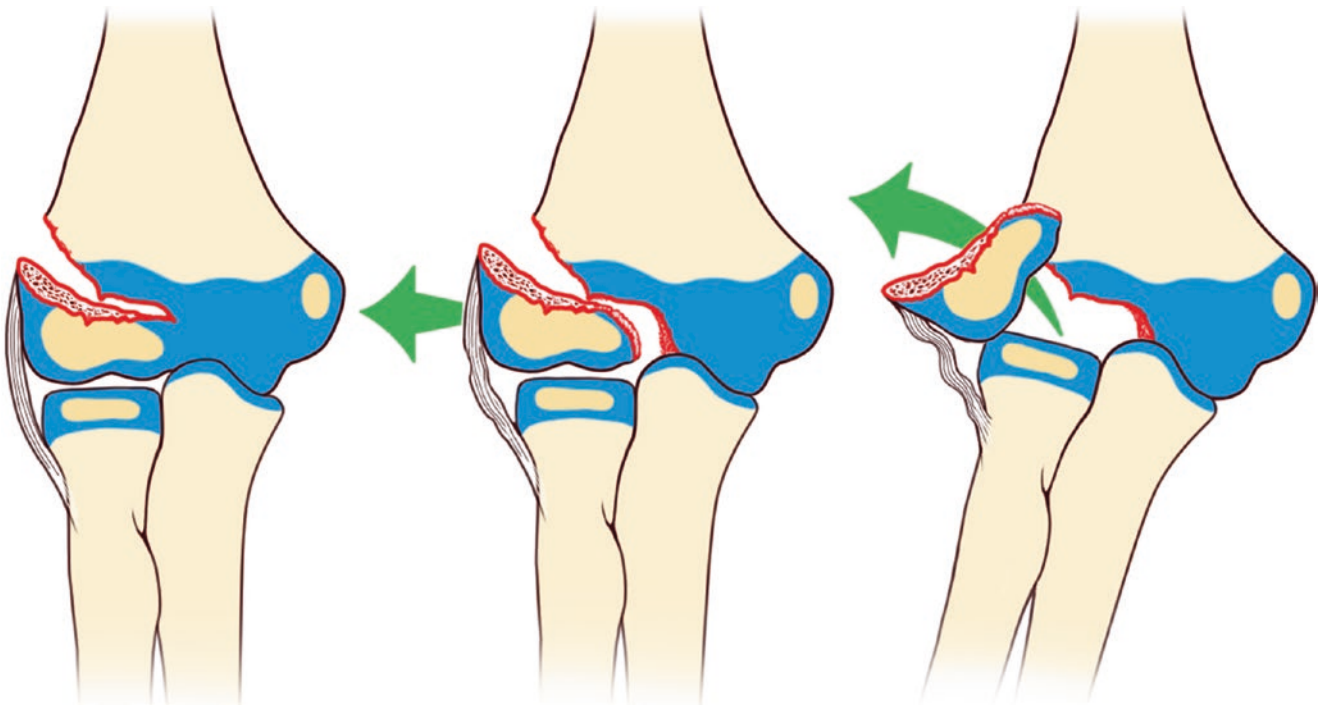


Fig. 20.17 Lateral condyle fracture: Jakob classification

– C: fracture gap equal both medially and laterally (increased risk for displacement).

Fracture gap:

– Type 1: un-displaced fracture (<2 mm) with articular surface intact
– Type 2: minimally displaced fracture (2–4 mm gap) from the metaphysis
– Type 3: displaced fracture (>4 mm gap)

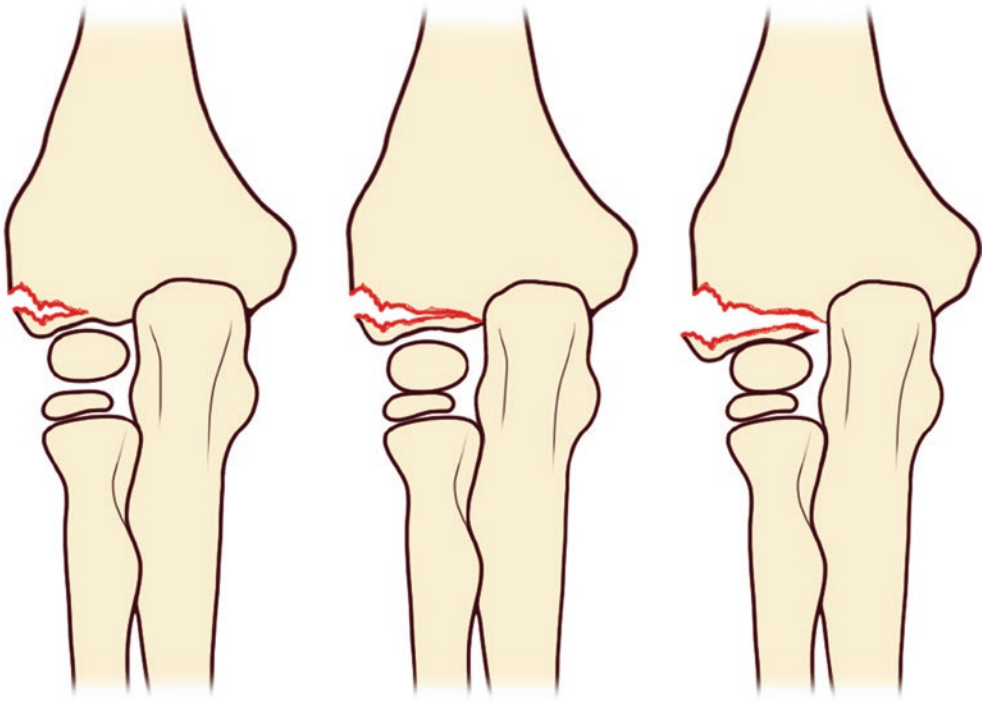


Fig. 20.18 Lateral condyle fracture: Finnbogason classification

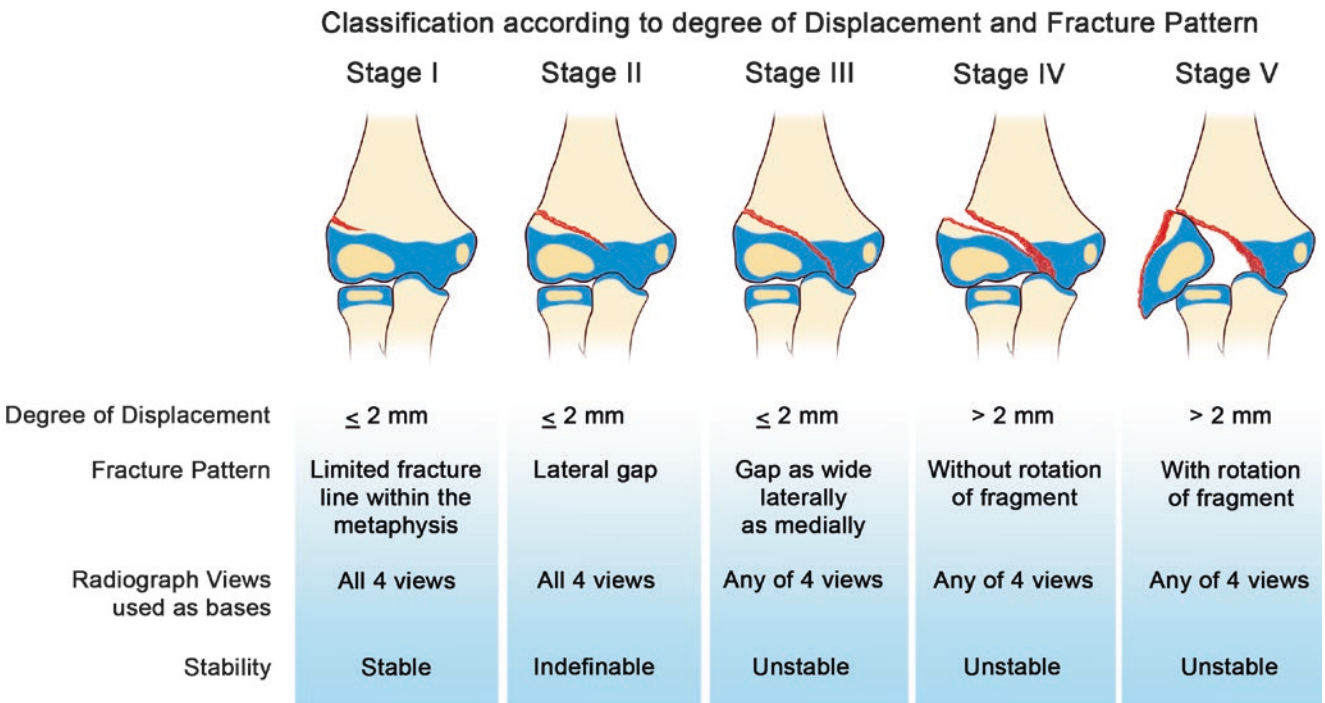


Fig. 20.19 Lateral condyle fracture: Song classification

Song (Fig. 20.19) (Song et al. 2008): *combination of degree of displacement, fracture pattern and joint stability*

Lateral condyle fractures are classified in five subgroups according to the amount of displacement and the fracture pattern as determined on the basis of the four radiographic views, with a special emphasis on the internal oblique view.

20.3.7 Presentation

The abnormal shape on the lateral side of the proximal forearm, due to soft tissue swelling, is a useful clinical aspect in the diagnosis of the lateral condyle fractures and in particular in the differential diagnosis with proximal radius and supracondylar fractures (Fig. 20.20).



Fig. 20.20 AP X-ray: abnormal lateral profile due to local swelling in lateral condyle fracture

20.3.8 Imaging

20.3.8.1 X-ray

The lateral condyle is the first centre to ossify between ages of 3 months and 2 years. It is important to remind that a reduced anterior angulation of the centre of ossification with a wider radiolucency on the posterior side of the physis in lateral view is physiological, especially in younger patients. Anteroposterior (AP), lateral, internal oblique and external oblique X-rays should be obtained to evaluate lateral condyle fractures. Internal oblique view most accurately shows maximum displacement and fracture patterns, allowing for a better diagnosis and treatment (Song et al. 2007).

The main radiological parameters considered are radiocapitellar line—anterior humeral line—Boumann's angle.

20.3.8.2 Ultrasound

The high-resolution ultrasound is an important diagnostic option to evaluate the continuity of cartilaginous hinges and displacement. It is safe, more accessible than an MRI, non-invasive and executable without sedation even in young patients (Vocke-Hell and Schmid 2001; Zhang and Chen 2008).

20.3.8.3 MRI

It is particularly useful in the identification of potentially unstable fractures in the case of minimal displacement. However, this is an expensive exam, and it usually requires sedation in patients less than 6–7 years old (Kamegaya et al. 1999; Horn et al. 2002).

20.3.8.4 Arthrography

It is a relatively sensitive test for establishing the articular extension of the fracture. However, false negatives are possible due to haematoma which hinders the spread of the contrast fluid, the exam is painful and relatively invasive, there is a risk of infection and it requires radiation exposure. It is used to evaluate reduction in percutaneous pinning technique (Marzo et al. 1990).

20.3.9 Timing

The lateral condyle fractures are deferrable urgencies. In case of conservative treatment, a correct interpretation of fracture stability and an adequate radiographic follow-up are required. Delayed diagnosis of late displacement or non-union is not rare. In these cases surgical treatment should be carefully evaluated. Outcomes of acute surgical treatment are generally satisfactory, while delayed surgery is more difficult and associated with higher risk of stiffness and avascular necrosis of the fragment secondary to wide surgical exposure. Even if several reports in the literature have shown encouraging outcomes after treatments delayed by over 8 weeks, this option is generally reserved for symptomatic non-union/mal-union or severe deformity.

20.3.10 Treatment Algorithm

- Un-displaced fracture (<2 mm, cartilaginous hinge intact): conservative treatment
- Displaced fracture (>2 mm, cartilaginous hinge intact, not lateral/rotational displacement): closed reduction and percutaneous pinning
- Displaced fracture (>2 mm, interruption of cartilaginous hinge, rotational displacement, any joint incongruity after close reduction or CRPP): open reduction and fixation (two lateral pins or one pin + one extraphyseal screw)

Accurate weekly radiographical follow-up in the first 3 weeks is recommended in conservative treatment.

If open reduction is mandatory, the direct lateral approach (Kocher approach) provides an adequate exposure. It is essential to avoid dissection of the posterior aspect of the lateral condyle (source of vascularization), consider a possible plastic deformity or metaphyseal comminution of the

lateral column and verify the anatomic reduction of the articular surface. Lateral condyle fractures may frequently show a delayed union. Relative protection should be continued until radiographic consolidation that can also occur after 12 weeks, especially in conservative treatment (Price and Flynn 2006).

20.3.11 Complications

20.3.12 Minor Complications that Do Not Require Surgical Treatment

Lateral prominence/overgrowth: It is frequently due to osteogenic activation of the periosteal flap of the condylar fragment in conservative treatment or periosteal reaction to dissection after surgical treatment. This could result in a condylar hypertrophy with a clinical pseudo-cubitus varus. It is recommended to advise parents of this possible evolution caused by biological features (Fig. 20.21).

Fishtail deformity: It is related to the gap between the lateral condyle and ossific nuclei of trochlea or to disruption of the lateral trochlear epiphyseal vessels resulting in an early arrest of development. Generally, it does not create a severe functional deficit.

Superficial infection: It usually resolves after removal of the pin.



Fig. 20.21 Clinical example of pseudo-cubitus varus of the left elbow after conservative treatment of lateral condyle fracture

20.3.13 Major Complications that Could Require Surgical Treatment

Cubitus varus: It is the most frequent complication that occurs in both conservative and surgical treatment. It could be secondary to inadequate reduction combined with post-traumatic overgrowth at the lateral condyle (Fig. 20.22a) or to non-union (Fig. 20.22b), with possible severe instability.

In most cases it remains a mild deformity, does not present a rotational component and usually not require treatment.

Cubitus valgus: It is secondary to non-union and proximal migration of the condylar fragment, with progressive cubitus valgus and possible tardy ulnar nerve palsy (Fig. 20.23a, b).

Elbow instability: It is frequently associated with non-union (either in valgus or varus cubitus).

Mal-union: It may result in stiffness which is very difficult to solve even surgically with intra-articular osteotomies (Fig. 20.24a, b) (Bauer et al. 2013).

Avascular necrosis: It may be iatrogenic and is most commonly associated with the extensive dissection necessary to perform a late reduction or from loss of the blood supply at the time of injury. Overly aggressive dissection of fresh fractures can result in osteonecrosis of either the lateral condylar ossification centre or, rarely, the metaphyseal portion of the fragment, leading to non-union. Any residual deformity is generally related to loss of motion (Fig. 20.25) (Kasser and Beaty 2006b).

20.3.14 Medial Epicondyle Fractures

Fractures of the medial epicondylar apophysis account for about 11% of all elbow fractures in children. They usually occur in children (9–12 years old) and adolescents due to the fact that the medial epicondyle is the last growth centre to ossify and coalesce in distal epiphysis of the humerus. The

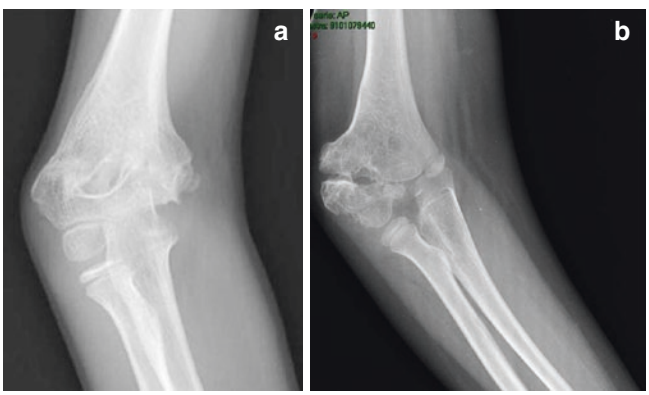


Fig. 20.22 AP X-ray: cubitus varus secondary to insufficient reduction (**a**) and nor-union of the lateral condyle (**b**)

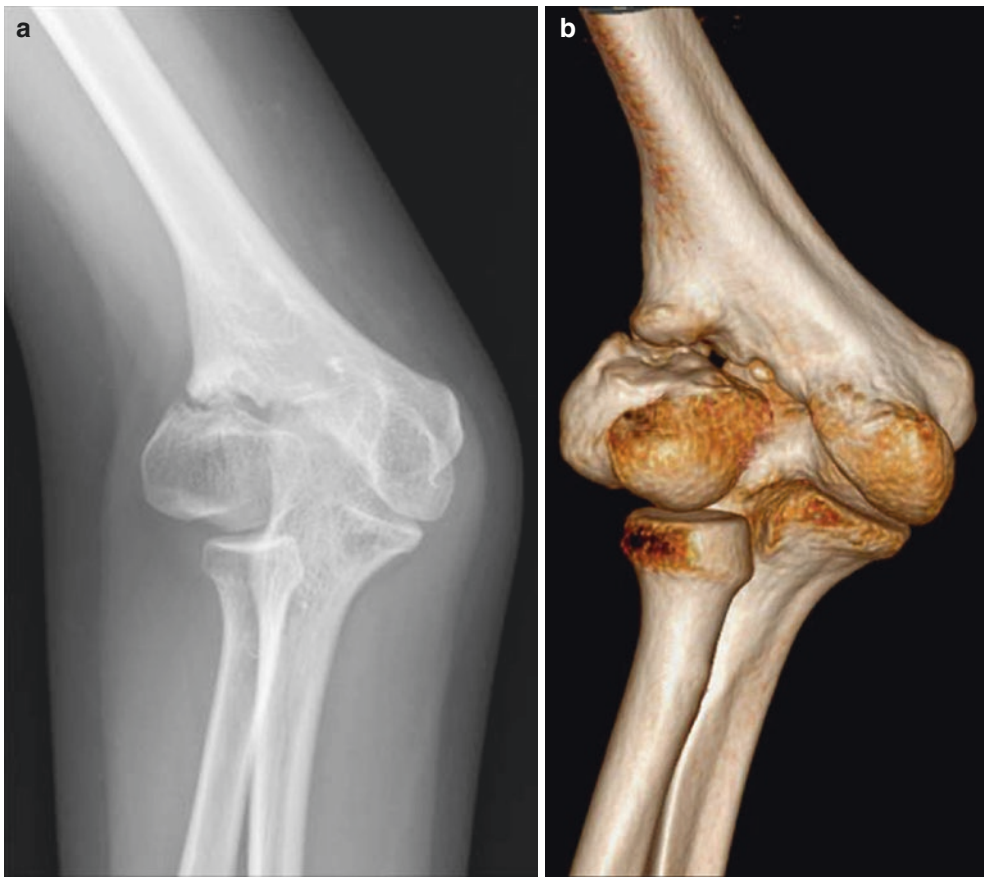


Fig. 20.23 AP X-ray (**a**) and 3D CT scan reconstruction (**b**): non-union of the lateral condyle with proximal migration of the fragment, cubitus valgus, elbow instability

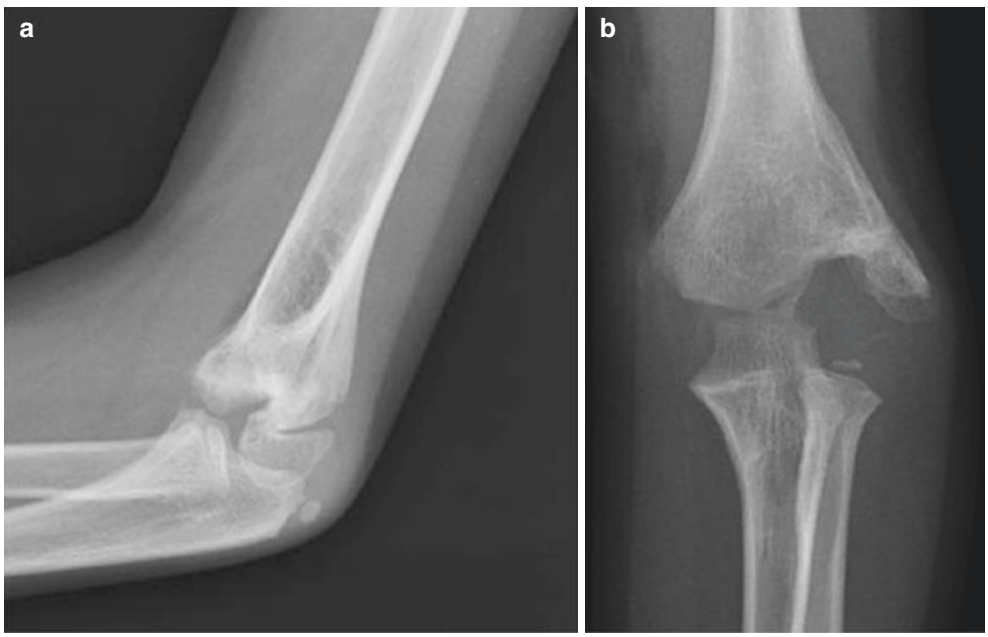


Fig. 20.24 LL X-ray: malunion of the lateral condyle with posterior translation (**a**) and rotation (**b**) of the fragment



Fig. 20.25 AP X-ray: avascular necrosis of the lateral condyle

apophysis, which is visible up to 17 years old, represents the point of least resistance: fractures of the medial epicondyle are Salter–Harris Type I or Type II fractures (with small fragments of metaphyseal bone). The male/female ratio is 4:1, due to sports or recreational activities.

The lesion is frequently associated with elbow dislocation (30–50% of cases), or it represents the residual sign after the reduction of an elbow dislocation (Kasser and Beaty 2006b. In 15% of cases, the fragment may be incarcerated in the joint after a spontaneous reduction (Wilkins 1990) (Fig. 20.26).

The most common traumatic mechanism is a fall on an outstretched hand with the elbow in full extension, resulting in sudden traction of the flexor pronator muscle group of the forearm together with valgus stress on the elbow (fracture of proximal radius or olecranon can also occur) (Kasser and Beaty 2006b).

A chronic injury with a valgus subluxation mechanism can occur in overhead throwing athletes: X-rays show in these cases irregularity and widening of the physis (Brogdon 1960).

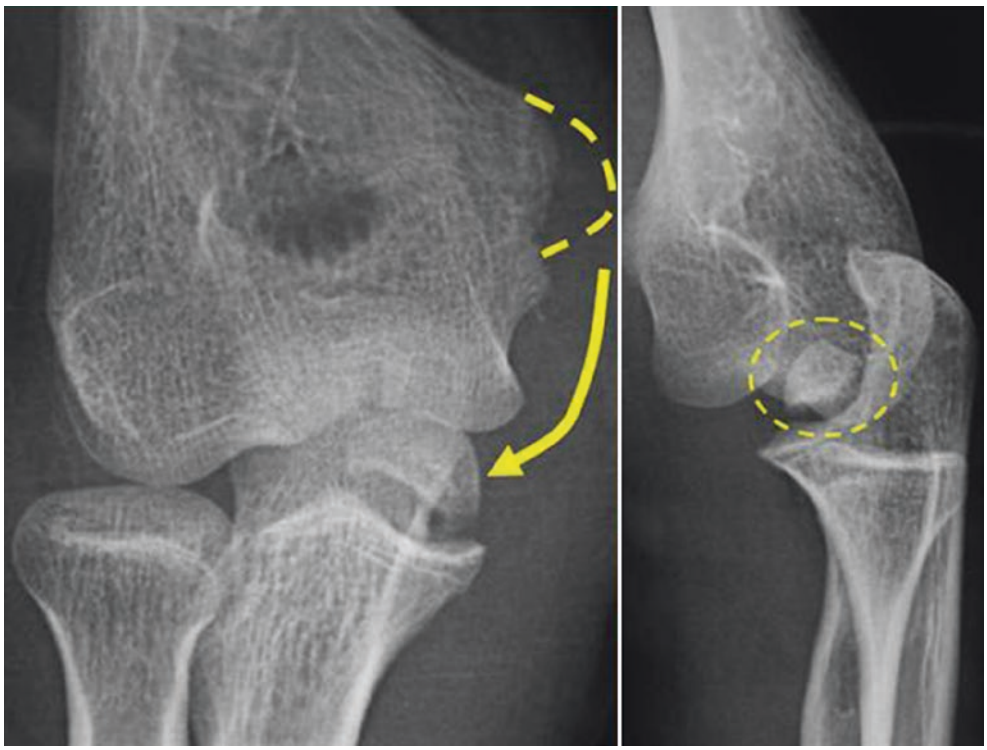


Fig. 20.26 X ray after reduction of elbow dislocation. Intra-articular incarceration of the epicondylar apophysis

Classification:

- Un-displaced or minimally displaced fracture (slight increase of radiographic radiolucency)
- Displaced fracture: >5 mm displacement
- Fracture incarceration in elbow joint
- Stress fracture

20.3.15 Presentation

Soft tissue tenderness and swelling at the medial aspect of the elbow are usually present.

A crackling is perceptible during palpation in case of minimally displaced fractures, while a mobile fragment can slide in the case of a displaced fracture (widespread edema due to high-energy trauma). It is important to investigate the traumatic dynamics and determine any self-reductive manoeuvres of a dislocation. In the case of a reduction in passive extension, the epicondyle may be incarcerated in the joint. Varus-valgus stability is evaluated with the patient supine on table with arm abducted to 90° and elbow flexed to 15°.

Ulnar nerve paresthesia is common. (Smith 1950).

20.3.16 Imaging

X-rays are usually sufficient to assess a wider radiolucent line or a loss of parallelism of the smooth margins of the physis (Silberstein et al. 1981). A comparison to the contralateral side may be useful in case of doubt. The avulsed centre of ossification usually does not reach the joint, but careful evaluation of the joint line is essential if the centre of ossification is not visible.

Differential diagnosis with medial condylar fracture involving articular surface has to be considered in younger patients when trochlear centre has not yet appeared (Fig. 20.27). An MRI

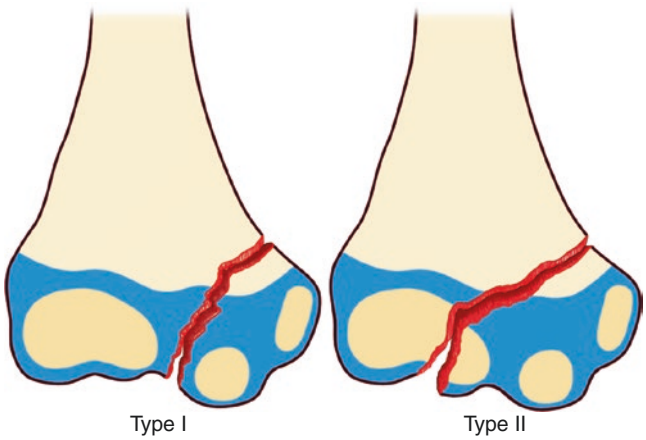


Fig. 20.27 Differential diagnosis with medial condylar fracture involving articular surface is very important in younger patients (Milch classification)

can be appropriated in case of haemarthrosis or large metaphyseal fragment in the X-ray (Beaty and Kasser 2006).

20.3.17 Surgical Treatment

Absolute indication for open reduction and internal fixation:

Fracture with articular incarceration of the medial epicondyle (Pimpalnerkar et al. 1998; Dodds et al. 2014).

Relative indication for surgical treatment:

Fracture associated to elbow dislocation
Significant displacement with valgus instability
Fractures with associated ulnar nerve dysfunction
Athlete with high functional demand

Conservative treatment of un-displaced or minimally displaced fractures is generally agreed on in literature, while treatment of displaced fractures is debated.

Many authors have reported good results after conservative treatment also in displaced fractures, with good functional results even with a relatively high percentage (up to 50–60%) of radiographic pseudoarthrosis with fibrous non-union (Kasser and Beaty 2006b; Josefsson and Danielsson 1986; Farsetti et al. 2001). Other authors highlight better functional results after surgical treatment and recommend stabilization with K-wires or cannulated screws in cases of displacement >5 mm (Lee et al. 2005; Dunn et al. 1994). Generally ulnar nerve anteposition after internal fixation is not necessary.

20.3.18 Treatment Algorithm

- Un-displaced or minimally displaced fractures: elbow cast or splint for 4 weeks, self-managed mobilization after 3 weeks
- Displaced fractures (>5 mm): conservative treatment or open reduction and internal fixation (most authors consider surgical treatment in these cases)
- Fractures associated with articular incarceration of the medial epicondyle fragment: open reduction and internal fixation

20.3.19 Complications

Elbow joint stiffness, usually mild (<15°), is the most frequent complication, after both surgical and conservative treatment. An adequate explanation of the problem to parents, emphasizing the need for relatively early and regular mobilization is important (some authors suggest in un-displaced fractures a gentle self-assisted joint mobilization at 2 weeks) (Bernstein et al. 1981; Skaggs 1997).

Even with fractures accompanying elbow dislocation, symptomatic instability is uncommon. However, there are some reports in literature of cases of progressive valgus deviation with elbow instability due to the non-union associated with significant migration of the ossification centre after conservative treatment and failure of internal fixation (Gilchrist and McKee 2002).

20.4 Radial Head and Neck Fractures

Radial head and neck fractures account for 5–10% of all elbow fractures in children and for 1% of all paediatric fractures. The peak age of incidence is between 9 and 12 years old.

The most common mechanism is an indirect trauma, with most resulting from a fall onto an outstretched arm with minimal or moderate flexion of the elbow joint and valgus stress.

In 30–50% of cases, they are associated with other injuries such as elbow dislocation, medial epicondylar fractures or olecranon fractures (Fig. 20.28) (Eilert and Erickson 2006b). The proximal radial physis only contributes 20% to the longitudinal growth of the bone. Consequently, the remodelling potential, compared to distal radius, is lower and often incomplete.

It is important to remember that the full maturation of the proximal radial physis may be relatively late (14–17 years old), and the epiphysis has a physiological lateral angle in the coronal plane of about 12.5° and an anterior angle in the sagittal plane of about 3.5° (Vahvanen 1978).

20.4.1 Classification

The most simple classification system describes the radial head fractures according to Salter (Type I and II the most frequent, Type IV with joint involvement the most rare) or to degree of angulation in the coronal plane (O'Brien (1965)):

- Slight (<30°)
- Mild (30–60°)
- High (>60°)

Metaizeau classification (modified Judet classification) (Metaizeau 1980):

- Grade I: 0° angulation with translation
- Grade II: angulation of less than 30°
- Grade III: angulation of 30–60°
- Grade IV a: angulation of 60–80°
- Grade IV b: angulation of more than 80°

Others authors classify the proximal radius fracture according to fragment displacement related to the metaphysis or according to extension of the fracture line or mechanism of the injury.

Steele–Graham classification according to displacement and angulation (Steele and Graham 1992):

Grade 1: angulation 0–30°—translation 0–10%
Grade 2: angulation 31–60°—translation 11–50%
Grade 3: angulation 61–90°—translation 51–90%
Grade 4: angulation >90°—translation >90%

Chambers classification (Beaty and Kasser 2006):



Fig. 20.28 Radial head fracture associated with olecranon fracture

- GROUP 1: Primary displacement of radial head (most common)
  - Valgus injury
    Type A: Salter–Harris I or II with metaphyseal fragment
    Type B: Salter–Harris IV (metaphyseal and epiphyseal fragment with articular surface involvement)
    Type C: Fractures involving only the proximal radial metaphysis
  - Elbow dislocation
    Type D: reduction injury
    Type E: dislocation injury
- GROUP 2: Primary displacement of radial neck (Monteggia variant)
- GROUP 3: Stress injury (osteochondritis dissecans)

20.4.2 Presentation

Pain and tenderness along the posterolateral aspect of elbow (anconeus triangle) and limited passive elbow/forearm motion are present.

20.4.3 Imaging

The main radiographical parameters considered are coronal/sagittal angulation and translation—displacement related to the metaphysis.

Ultrasound and MRI represent important diagnostic option for determining any displacement of the unossified radial head (Vocke-Hell and Schmid 2001; Zhang and Chen 2008).

20.4.4 Treatment Algorithm

There is no complete agreement in the literature regarding which initial angle is acceptable to perform conservative treatment.

The skeletal age of the patient is very important because remodelling potential decreases in patients older than 10 years.

Some authors suggest conservative treatment without reduction in the case of fractures with angulation ≤30° (Eilert and Erickson 2006a; Steele and Graham 1992).

Closed reduction is usually required in the case of fractures with an angular deformity greater than 30° (range 20–45°); in these fractures the surgical trauma seems to have a negative impact on final outcome. The reduction may be performed with manipulation, applying traction to the supinated forearm and thumb pressure to fragment with elbow in varus deviation. The goal is to obtain an angular deformity of less than 30°, a translation of less than 3 mm and a passive supination/pronation more than 50–60°.

Many authors suggest avoiding closed reduction in fractures with severe angular deformity (range 45–70°). When reduction is not achieved, percutaneous techniques are indicated (K-wires or Steinmann pins with percutaneous or mini-open approach under fluoroscopy) (Feray 1969).

Range of motion should be checked at the end of reduction. If reduction is stable, fixation is not necessary.

It is also possible to reduce and fix the displaced fragment with retrograde intramedullary technique through a distal radial approach (Metaizeau technique) (Fig. 20.29) (Eilert and Erickson 2006b; Metaizeau et al. 1993; Metaizeau 2005).

Open reduction is indicated when closed reduction fails or in complete displacement with high angulation or loss of metaphyseal connection; generally the Kocher approach provide a good exposure avoiding injury to the anterior interosseous branch of the radial nerve. Internal fixation is performed using one or two K-wires or a retrograde intramedullary nail.

20.4.5 Treatment Algorithm

Simple immobilization:

Angulation (<30–45°), <10 years old
Angulation (<20–30°), >10 years old

Immobilization after closed reduction:

(Thumb pressing, K-wire leverage method, closed intramedullary fixation of Metaizeau)
Angulation (>30–45°), <10 years old
Angulation (>20–30°), >10 years old

20.4.6 Open Reduction

Angulation (>45–70°) after failure of closed reduction
Completely displaced fractures with loss of metaphyseal connection

20.5 Results

Many authors use the evaluation criteria of Steinberg et al. (1988) and Rodriguez-Merchan (1994), which are relatively simple and comparable:

– Good result: complete range of motion, no pain
– Fair result: loss of 20° of ROM in any plane of motion (supination/pronation or flexion-extension) or mild pain

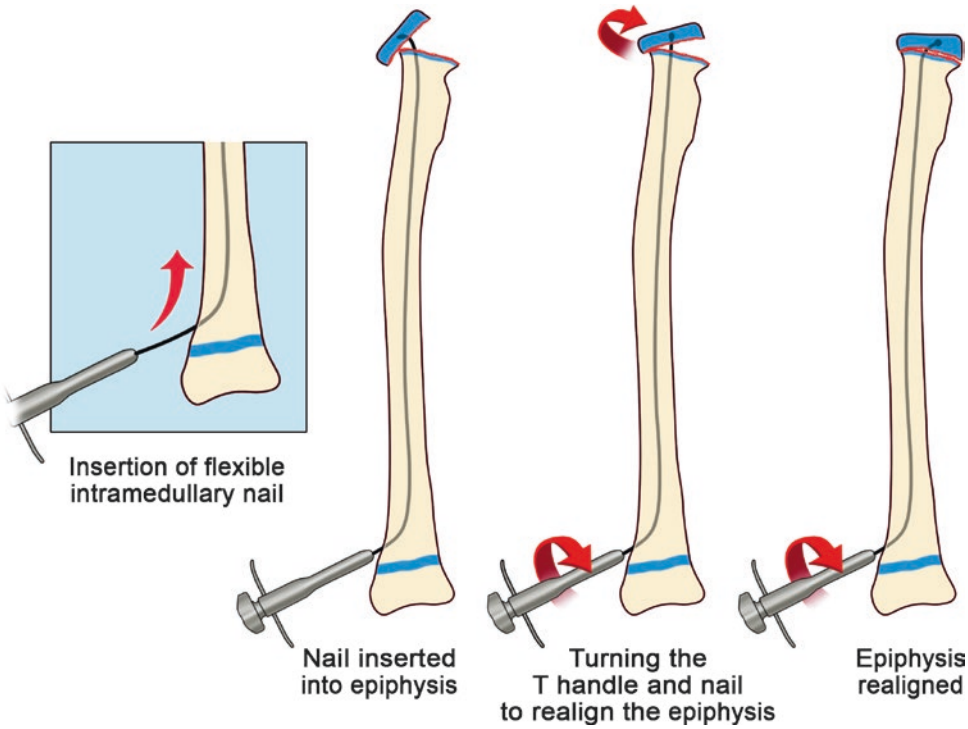


Fig. 20.29 Retrograde intramedullary reduction technique through a distal radial approach (Metaizeau technique)

– Poor result: loss of more than 20° of ROM in any plane of motion or pain

It is important to note that negative results in 15–30% of cases are reported in literature and that up to 50% of patients treated for severe displacement report a limitation in pronation and supination.

Negative prognostic factors are age >10 years, residual angulation >30° or translation >3 mm, delayed treatment, the presence of associated injuries and an open reduction (Vocke and Von Laer 1998; Neher and Torch 2003).

20.5.1 Complications

20.5.1.1 Articular Stiffness

It is due to mal-union associated with articular incongruity and fibrous adhesions. It can sometimes occur after a relatively "innocent" fracture or after non-invasive treatment. Loss of pronation is more common than loss of supination. Flexion and extension rarely are significantly limited (Rodriguez-Merchan 1994; Bernstein et al. 1993; D'Souza et al. 1993).

20.5.2 Radial Head Overgrowth

Overgrowth is the most common consequence together with articular stiffness (20–40%). It is probably due to the increase in local vascularization secondary to an epiphyseal fracture. It does not compromise the functionality, even if clicking can occur during supination/pronation (Eilert and Erickson 2006b; Vahvanen 1978).

20.5.2.1 Osteonecrosis (Fig. 20.30a)

The ischaemic damage is related to the severity of the displacement and to the surgical technique (up to 25% of the cases treated with open reduction). Necrosis is usually only partial due to a relative revascularization and is generally well tolerated with satisfying functional results (Eilert and Erickson 2006b; D'Souza et al. 1993).

Mal-union: results from failure either to achieve adequate reduction or to maintain reduction. It may also result from premature fusion of upper radial epiphysis that occurs frequently in displaced fractures; this will cause shortening of the radius and cubitus valgus, depending on patient age and degree of cartilaginous damage (Eilert and Erickson 2006b).

Intra-articular ossifications (Fig. 20.30b)

It is usually related to soft tissue damage during surgery, generally limited to the supinator muscle.

20.5.2.2 Non-union

It is rare and related to the interposition of a periosteal flap or to an aggressive surgical approach with vascular damage. However, a fibrous pseudoarthrosis can still ensure sufficient stability and good function (Eilert and Erickson 2006b; Scullion and Miller 1985).

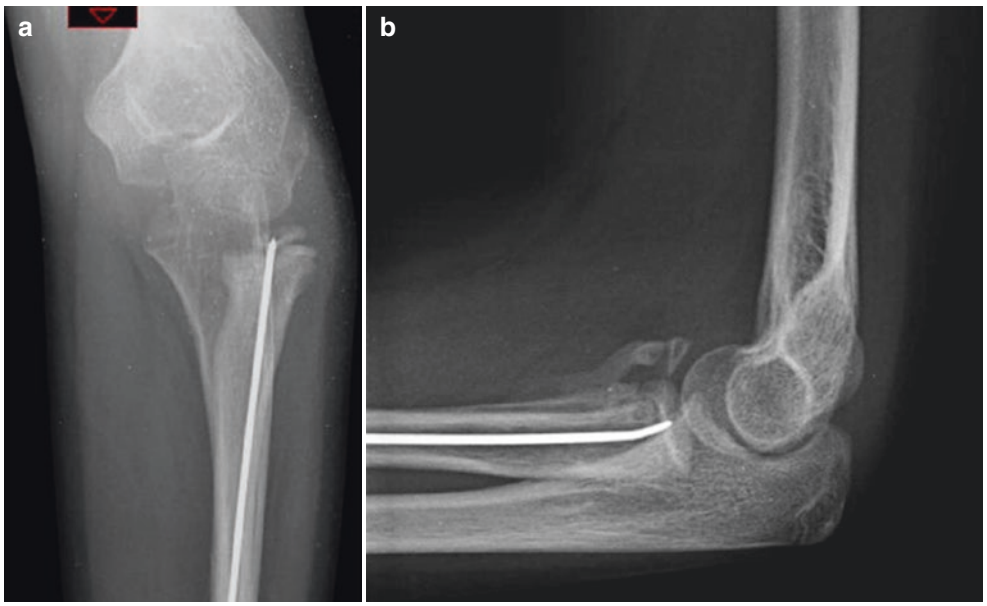


Fig. 20.30 Ischemic damage of the radial head (**a**) and anterior ossification (**b**) after open reduction and retrograde osteosynthesis

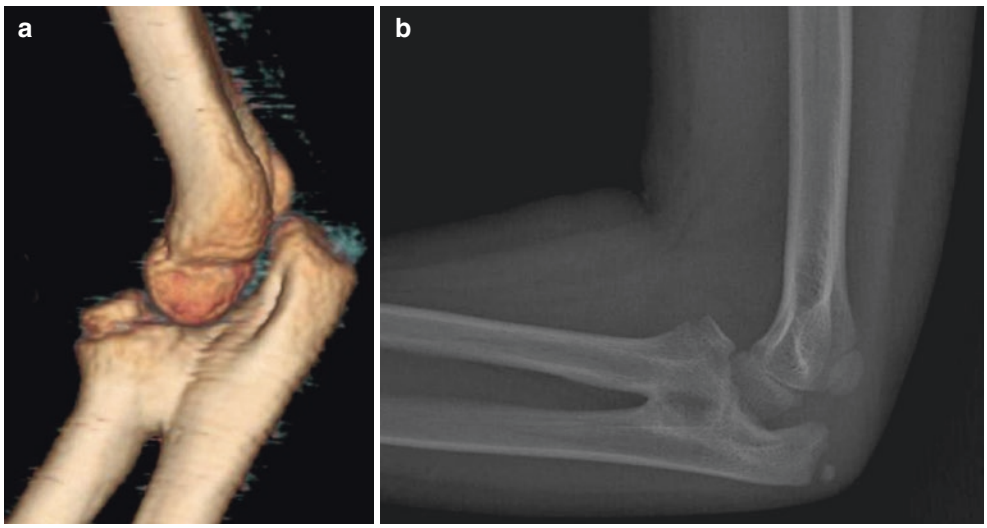


Fig. 20.31 Radial head malunion (**a**) and proximal radio-ulnar synostosis (**b**) 6 months after failed open reduction

20.5.2.3 Radio-Ulnar Synostosis (Fig. 20.31a,b)

It's a serious complication that can occur after open reduction of severely displaced fractures but also after closed reduction. Delayed treatment (>5 days) increases the likelihood of this complication (Gaston et al. 1953).

20.5.3 Rehabilitation Treatment in Paediatric Elbow Fractures

Discussing rehabilitation of paediatric elbow fractures, literature describes similar results at 6 and 12 months for children treated conservatively, with a close reduction and percutaneous pinning or open surgery, whether or not rehabilitation was performed (Keppler et al. 2005; Schmale et al. 2014). However, in these studies rehabilitation was not carried out with an intensive protocol but performed occasionally, without a detailed description of the therapeutic programmes.

Some authors state that in the short term the range of motion is better recovered in children treated with proper rehabilitation highlighting that the final prognosis is not, as in adults, related to the rehabilitation treatment (Schmale et al. 2014) but dependent on the child's age and duration of immobilization: the longer the time of restraint, the worse the prognosis and incidence of stiffness. According

to others also the grade of displacement of the fracture is a prognostic factor (Morrey 2005; Bernthal et al. 2011). It should be kept in mind that the emotional component has a greater relevance in surgical treatment over conservative and percutaneous pinning, with an influence affecting compliance of the child to the therapeutic performance of the exercise making rehabilitation treatment more challenging.

After these considerations, in order to report our experience with physical therapy after paediatric elbow fractures, it is first necessary to consider the various types of elbow fractures. The most common area injured is the supracondylar, followed by lateral condylar fractures, medial epicondylar fractures, fractures of the olecranon, radial head and neck and medial epicondyle. These fractures, depending on their severity, are all cured by conservative treatment, closed reduction and percutaneous pinning (CRPP), open reduction and internal fixation.

It is therefore possible to identify two different rehabilitation treatments: the first includes children treated conservatively with plaster cast or by closed reduction, percutaneous pinning and plaster cast; the second rehabilitation treatment includes cases treated by open reduction and internal fixation with K-wires and cast immobilization.

Conservative treatment or closed reduction and CRPP are indicated for supracondylar fractures of the distal humerus without open fractures, peripheral ischaemia or vascular impairment after a reductive manoeuvre, lateral condyle fractures, un-displaced or minimally displaced medial epicondyle fractures and radial head and neck fractures. In these cases immobilization is maintained for 3–4 weeks, but relative protection should be continued until radiographic consolidation that can also take up to 12 weeks for lateral condyle fractures. During this period mobilization of the shoulder and fingers is recommended. Shoulder mobilization avoids contractures of the upper trapezius and pectoral and capsule retraction, maintaining a wide range of motion. In younger children these exercises are usually carried out with parental assistance, while older children learn to perform self-mobilization with the help of the opposite limb. Mobilization of the fingers consists in movements of active flexion-extensions by opening and closing the hand with the aim of activating the vascular pump to avoid oedema of the hand. Generally after 3–4 weeks, cast and pins are removed; the child keeps the limb protected in a 90° brace for 2 weeks with removal only for gentle mobilization and aquatic therapy. For this group our advice is to actively perform self-assisted rehabilitation exercises. Studies (Zionts et al. 2009) on children treated conservatively with CRPP show that in 6 months 94% of cases have a range of motion (ROM) in flexion-extension comparable to that of the opposite elbow and in 98% of cases this occurs at 12 months (Spencer et al. 2010). Parents should be informed that in these cases a dedicated rehabilitation treatment is unnecessary and it takes at least 3 months for a functional ROM and a year for a full ROM. In fact, as indicated by Blount (1955): “the child instinctively knows better than the parents, the physiotherapist and the doctor what he can do without harming”. At 2 months the child can start physical activity to improve the obtained ROM, because unlike adults children can improve up to a year after the trauma. Competitive sports activity can be resumed when the elbow has recovered 90% of the ROM.

The second rehabilitation treatment is performed on children treated by open reduction and pinning, followed by plaster cast immobilization for 4 or more weeks.

Open reduction and internal fixation are indicated for supracondylar fractures of the distal humerus with open fractures, peripheral ischaemia or vascular impairment after a reductive manoeuvre and irreducible fracture, displaced fractures of lateral condyle, fractures with articular incarceration of the medial epicondyle or associated to elbow dislocation, ulnar nerve palsy due to entrapped nerves, athletes with high functional demands, radial head and neck fractures with severe angular deformity or completely displaced fractures with loss of metaphyseal connection. During the period of immobilization, the child performs exercises for the shoulder and hand as previously described, and at cast removal a specific rehabilitation programme with the assistance of a therapist is started. The need of outpatient rehabilitation treatment after open reduction is related to scar tissue, increased pain, swelling, loss of muscle mass and the apprehension of patients.

Child rehabilitation treatment requires a specific therapist expert in paediatric rehabilitation, working in a proper child environment using dedicated tools. Child rehabilitation consists of different components that must match: the rehabilitation setting where the treatment takes place, the role of the therapist, the child and the parents, the fun role of the exercises and the situation created by the proposed action. An adequate location is essential to motivate what the child is going to do; it must therefore be a privileged space, prepared and adjusted according to the child’s treatment necessities, and the child should identify it as a comfortable and familiar space.

Concerning role, neither the therapist nor the child acts for their role. At every meeting the choice of roles must be negotiated, adjusting the therapist’s ideas to the activities to be performed, with the desires and experiences the child may have undergone during previous sessions. Through the role played by the therapist and that played by the child, the therapist can establish a therapeutic alliance with the little patient which is mandatory for interaction.

In order to simplify the child's recognition of the place and role identification, it is essential to use objects such as toys especially chosen for the goals that are to be achieved. Tools used must be common and real toys, so that it is easier for children to transfer the learned skills from the therapeutic setting to everyday life. The proposal is represented by what the therapist asks the child to do during the session. This is the essential condition for the child to be induced to change its functions in an adaptive way (Ferrari and Cioni 2005).

Rehabilitation treatment aims to recover range of motion (ROM), strength and upper limb function. For recovery of ROM, to start off it is important to mobilize the scar, especially after a posterior approach required in supracondylar fractures of the distal humerus, mostly in the early weeks after cast removal, in which the formation of triceps adhesions is frequent, causing loss of motion in flexion. Scar tissue mobilization must be done both on the superficial and deep level, with manoeuvres such as Pince Roule, deep transverse massage and deep tissue massage; recently kinesiotaping was included among mobilization methods.

Recovery of ROM in flexion-extension (Figs. 20.32 and 20.33) has the aim of decreasing adherent scar formation, facilitating healing of the cartilage and improving peripheral circulation. To prevent myositis ossificans, which can involve the brachialis muscle, mobilization exercises must be in active-assisted ROM (AAROM), and forced mobilization of the operated elbow is not recommended. In fact, exercises in AAROM involve low levels of muscle recruitment and less stress on the joint. Exercises must be carried out in positions that do not destabilize the elbow. Active mobilization exercises allow activation of both agonists and antagonists (Fig. 20.34), stimulate the proprioceptors by inhibiting pain and recruit intra- and extrafusal fibres reducing the co-contraction of the antagonists. Fundamental is the contraction of the triceps, which is a dynamic stabilizer of the elbow joint. Pronation/supination is performed starting with the elbow at 90° and then progressively at major extension angles. Application of controlled heat prior to exercise is useful to improve joint function recovery. The intensity of active exercises associated to reinforcement of epicondylar or epitrochlear muscles is gradually increased. Strength and resistance exercises are performed by contrasting flexion-extension and pronation-supination with weights and rubber bands: the exercises should be performed with high frequency and low intensity. If stiffness persists, it is indicated to proceed with low load long duration stretching exercises, using specific elastic bands and postures.



Fig. 20.32 Active elbow mobilization in flexion



Fig. 20.33 Active elbow mobilization in extension



Fig. 20.34 Proprioceptive exercises

In supracondylar fractures elbow stiffness is due to malunion in extension, rotation defects or protracted postoperative immobilization, in lateral condyle fractures to residual deformity. In medial epicondyle fractures, elbow joint stiffness is usually mild; in radial head and neck fractures, loss of pronation is more common than loss of supination. Flexion and extension rarely are significantly limited. When the elbow tends to become stiff, specific flexion-extension and pronation-supination mobilization braces can be used from the second month (Fusaro et al. 2014). Both literature and experts give no indication as to when the application of mobilization braces can lead to best functional results. In our experience the use of a mobilization brace is indicated when the child or parents are poorly motivated to perform regular exercise or when there is no clinical evidence of ROM recovery. Braces should not be used earlier than 3 months after the surgical procedure, and usually the best results are achieved 4–6 months from the trauma.

Among the mobilization braces available on the market, we prefer the static rather than the dynamic because there is no continuous stress on the elbow, but alternate cycles of tensioning and rest of the capsule-ligamentous structures, avoiding a possible exacerbation of the inflammatory phase.

Pronation-supination mobilization braces are custom-made double splints, tensioned by straps. These braces can be used in stiffness secondary to fractures of the radial head, which usually have a reduction of pronation-supination motility of variable grade, while this movement is usually not affected in supracondylar fractures. Flexion-extension and pronation-supination mobilization braces should be used full time and removed four to five times a day to perform active mobilization. To improve the results achieved, at the end of the rehabilitation treatment, it is useful to suggest an adapted physical and aquatic activity for the child.

Supracondylar fractures can be associated to primary neurological injury of the anterior interosseous nerve and the posterior interosseous nerve; in secondary neurological injuries, the ulnar nerve is the most frequently involved. These are generally neurapraxia paralyses and therefore the outcome is benign.

Treatment of peripheral paralyses is usually done by mobilizations in direction opposite to the deformity associated with bracing to prevent shortening of the affected muscles until restoration of nerve activity. Neuromuscular facilitation techniques can be used to improve the recruitment of motor units, and when tolerated by the child to avoid acinesia metaparalitica, it is useful to associate exponential electrotherapy on paretic muscles.

Paralysis status is controlled every 2 months by clinical examination, neuroelectric exam with intensity-time curves or and by electromyography in more compliant older children; if after 4 months signs of recovery are not evident, a surgical solution may be indicated.

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Sequels of Treatment in Children's Traumatic Lesions

21

Maria C. Marongiu, V. Luppi, and Claudio Rovesta

21.1 Introduction

The elbow is the second most common site of skeletal traumatic injury in children and adolescents.

The elbow injuries in the pediatric population are divided into the distal humerus and proximal forearm. In the distal humerus, we distinguish the extraarticular fractures (60% supracondylar fractures and epicondylar fractures) from intraarticular or transcondylar fractures (like fractures of the lateral condyle or medial condyle and Y fractures). In the proximal forearm, we distinguish fractures of the proximal radius (head of radius) and fractures of the proximal ulna (olecranon) (Beaty and Kasser 2008; von Laer 2004).

Elbow dislocation (usually posterolateral dislocation) with or without associated injuries occurs in 5% of lesions. The isolated dislocation of the radial head and the Monteggia lesions are less frequent.

The numerous ossification centers, which appear on different age and fuse with each other at different times, sometimes are confusing in a diagnostic setting because they can often be mistakenly interpreted as fractures (Beaty and Kasser 2008).

Complications after injuries affecting a child's elbow are common due to underestimating the severity of the injury on the native X-rays where the growth plates and cartilage structures cannot be seen. Neglected lesions as avoiding to recognize and to diagnose the type of fracture, inadequate or unstable fixation, a failure to reduce the articular fragments, prolonged postoperative immobilization and the development of soft-tissue complications as stiffness, peripheral nerve compression will result in a disability for the patient (Muller et al. 2008).

The possibility and the speedy of spontaneous correction are dependent on the patient's age at the time of the trauma: the younger the patient is, the more rapid growth changes will be. The axial deviations in the main plane of motion of the body, the sagittal plane, are better corrected than deviations in the coronal plane. Post-traumatic deformities are caused either by residual axial deviations or by sequelae of growth disturbances (von Laer 2004).

Growth disturbances can occur in the form of transient lateral stimulation of the growth plate. However, they are of no clinical significance as they do not lead to any appreciable alteration of the axis of the elbow. Growth blockage from premature closure of the growth plate may result following repeated attempts to drill during percutaneous placement of Kirschner (K) wire (von Laer 2004).

The elbow is a hinge joint, and deformities lie outside this fixed plane of motion (axial deformities in the coronal plan, or cubitus valgus and varus) and then remain unchanged and are not corrected at all during the growth. These deformities can represent a significant cosmetic and social impairment for the patient.

The anterior bowing deformity of the fracture is caused by a trauma with the elbow in extension, and, depending on the age of the patient, it may be spontaneously corrected during growth, as it lies in the elbow's main axis of motion, the sagittal plane, and one may expect complete correction in younger patients (the threshold age is about 7 years).

The rotational deformity with respect to the axis of the elbow persists unchanged. In contrast the sign of a rotational deformity, the anterior or posterior rotational spur, may be relied upon to disappear, as it is largely absorbed. The rotational deformity can also be fully or partially "spontaneously" corrected as a result of physiological anteversion processes as it is in the femur, but in the humeral distal region, this does not appear to be the case (von Laer 2004).

The commonest complications by neglected situations are malunion (or angular deformity), nonunion, disturbances of growth (fishtail deformity), peripheral nerve deficit not recovered after 4 months, articular stiffness, and missed dislocation of the head of the radius, after conservative or operative treatment. Before any surgical indication, it is necessary

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for a physiatric evaluation to see if there is possibility of a further recovery by a rehabilitative treatment.

The indication of surgical correction of post-traumatic deformity depends on several factors: the severity, type, and evolution of the deformity (if the deformity increases, decreases, or remains constant over time), the patient's functional symptoms, the patient's age, and the cosmetic complaints by parents and patient. Sometimes if a distal humerus fracture is "skillfully neglected," a late pseudoarthrosis will be diagnosed, but no surgery is needed to a surprisingly good clinical function, in contrast to the X-ray findings (Muller et al. 2008).

The technically demanding reconstruction procedures of neglected lesions of the elbow include osteotomy for malunion, or debridement, realignment with stable fixation and autogenous bone grafts for nonunion, anterior or posterior capsulectomy in articular stiffness, simple neurolysis or neurolysis and anteposition (ulnar nerve) or nerve grafts in peripheral nerve lesions in continuity or pseudocontinuity, and simple reduction and annular ligament reconstruction or osteotomy of the ulna and radial reduction in neglected Monteggia lesions.

21.2 Angular Deformities (Cubitus Varus)

There are three components of the supracondylar displaced fracture pattern that contribute to the cubitus varus deformity: medial tilt or varus, internal (medial) rotation, and hyperextension. The deformity occurs as a result of residual coronal angulation (varus tilt) that is aggravated by malrotation and hyperextension.

The rotational deformity is only detectable in the lateral radiograph as an anterior spur or, rarely, as a posterior spur, formed by the proximal fragment.

The so-called carrying angle is the angle formed by the long axes of the humerus and the ulna with the elbow fully extended: in men, the mean carrying angle is 10–14°, and in women it is 13–16° (Fig. 21.1). A change in the carrying angle following a supracondylar fracture shows the varus (or rarely valgus) tilt. This can result from malunion, after inadequate or loss of reduction or as a result of growth disturbances of the lower end of the humerus. Residual internal rotation of the distal fragment predisposes it to collapse into medial tilt and hence produces the cubitus varus deformity (Kim et al. 2005; Beaty and Kasser 2008; von Laer 2004).

Cubitus varus deformity (gunstock deformity) is the most common late complication of all supracondylar fracture (30%) or of a physeal fracture of the distal humerus, apart from the method of treatment.

The causes of varus malunion of a supracondylar humerus fracture are failure to recognize the fracture (especially in those minimally displaced), not to reduce or to stabilize the malalignment (Papandrea and Waters 2000). New techniques of percutaneous pin fixation versus casting alone and closer postoperative observation for correction of the deformity have decreased the complication rate to less than 15% (Kim et al. 2005).

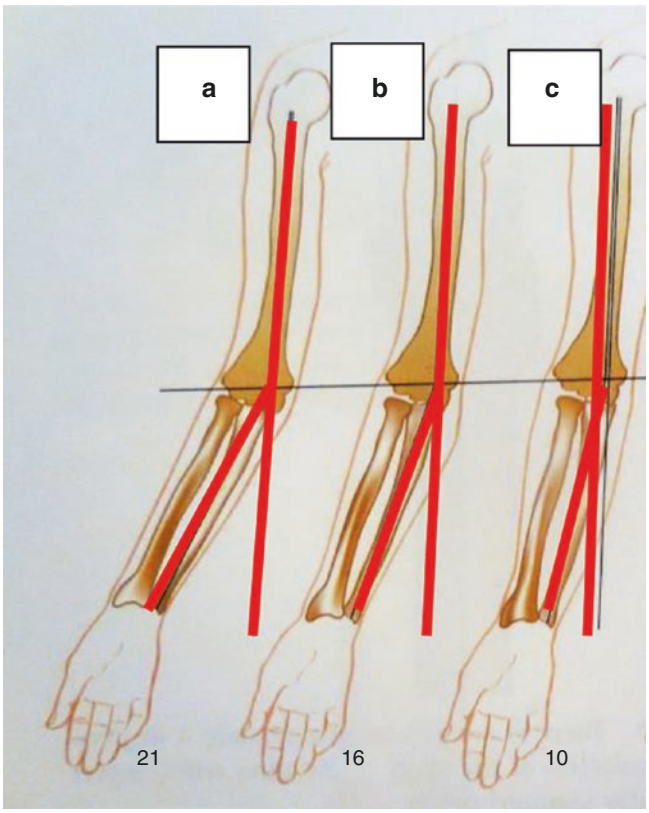


Fig. 21.1 *The carrying angle* is the angle formed by the forearm and the humerus (axis of humeral diaphysis and ulna) with the elbow extended. Normally it is from 10° to 16° (**b** and **c**). (**a**) Cubitus valgus

Cubitus varus occurs in approximately 42% of lateral condylar fractures, and it is believed to be secondary to a combination of lateral condylar physeal stimulation and inadequate reduction. Cubitus varus is less commonly due to trochlear osteonecrosis, and, in this case, the deformity is progressive (this is also known as malignant cubitus varus).

Lateral condylar spur formation results from overgrowth of the periosteal flap avulsed from the proximal fragment. The prominence could give the appearance of cubitus varus (pseudovarus). The overgrowth usually remodels the deformity, and the spur disappears, but spontaneous correction of cubitus varus during growth is unreliable (Wong and Lee 1990). The accuracy of the initial reduction best predicts the incidence of subsequent varus deformity in pediatric supracondylar fractures.

In post-traumatic cubitus varus, a minimal restricted motion of the elbow may be present, but function is rarely limited (Raney et al. 2012).

Initially thought to be of only cosmetic significance, the severe cubitus varus deformity has now been shown to have

many pathologically important consequences, including pain, epicondylitis, interference with sporting activities which increased the risk of lateral condylar fractures, tardy posterolateral rotatory instability (O'Driscoll et al. 2001), posterior shoulder instability, tardy ulnar nerve palsy, subluxation of the ulnar nerve, triceps snapping, paresthesias, and poor cosmesis. Cubitus varus deformity after lateral condylar fractures usually is mild and seldom is severe enough to determine concern or warrant surgical correction. Furthermore, the complication rates associated with corrective osteotomies average roughly 20%, with some sources reporting rates up to 33% (Ippolito et al. 1990; Labelle et al. 1982), including ulnar nerve palsy, hematoma, circulatory disturbances, loss of motion, sepsis, and cosmetically unacceptable scarring.

We controlled 90 patients, 50 boys and 40 girls, of average age 6, 6 years (min 1–max 13) with supracondylar fracture of the humerus (type 2–3 Garland) treated at our Orthopaedic Clinic of Modena in the period 1995–2011 with reduction and synthesis by K wires in 94%. In these patients we observed (average follow-up 43, 6 months, range 8 months to 132 months) a small reduction of the valgus compared to the contralateral elbow (less than 3°) in 32 patients. In six patients, the varus was higher (min 5°–max 14°), but none of these has been given a surgical indication of valgus correction for excellent mobility and functionality despite the cosmetic defect which still parents and patients gave no considerable significance (Fig. 21.2).

21.3 Surgical Treatment

The treatment of angular malalignment after supracondylar fractures includes hemiepiphysiodesis or osteotomy.

Hemiepiphysiodesis may be of benefit in case of medial growth arrest or trochlear avascular necrosis. Without treatment medial growth arrest leads to progressive worsening of varus deformity secondary to lateral overgrowth. Hemiepiphysiodesis is not indicated in the most common case of varus malreduction with a normal physis; in these cases it is preferred to use corrective osteotomy.

Various *osteotomies* have been reported in literature to achieve correction of post-traumatic cubitus varus. The types of osteotomies differ from:

- *Configuration* of the osteotomy: lateral closing wedge, medial opening wedge, and more complex three-dimensional configuration.
- *Mode of fixation*: casting alone, staples, two-hole plate, Steinmann pin, Kirschner pin fixation alone or in combination with screws to correct the rotational deformity, Y plate, Ilizarov external fixator, and uniplanar external fixator. Kirschner wire fixation is simple, can be used in a child with an open physis, and can be easily removed after union. Actually, external immobilization for 3–5 weeks is usually recommended with simple K-wire fixation. Plate and screw fixation offers the best stability and allows early movement of the joint, but usually there is not sufficient length for fixation of the distal fragment. The use of a cortical screw (Derosa and Graziano 1988) may be complicated by loss of fixation because of the narrow beak used. External fixation may be in the form of a simple uniplanar fixator or an Ilizarov ring fixator.
- *Surgical approach* to the distal humerus: medial, anteromedial, lateral, posterior, and posterolateral; this depends on the osteotomy to use.

Accurate preoperative radiographs of both elbows should be taken with the elbow fully extended, and the forearm supinated, so that the deformity may be accurately defined and compared with the normal extremity. A paper cutout model of the intended osteotomy may be helpful in decision of the degree of wedge excision necessary.



Fig. 21.2 P. M. 4 years old. *Right cubitus varus* as sequel of a supracondylar fracture 1 year ago (right carrying a006Egle <12° compared with left) evaluated in adduction (**a**) and abduction (**b**) of humerus

21.4 Configuration of the Osteotomy

The three most popular techniques are the lateral closing wedge osteotomy (LCWO), the step cut LCWO, and the dome rotational osteotomy.

The osteotomy performed most commonly, and the simplest procedure is the *lateral closing wedge osteotomy* (LCWO) as first described by Siris in 1939 (Bellemore et al. 1984). The patient was positioned supine, with the arm on a hand table. Posterolateral skin incision was made along the lower arm. The lateral third to half of the triceps muscle was reflected from its insertion. After subperiosteal exposure of the distal humerus, the osteotomy site was marked on the humerus with the help of template which determine the length of the lateral wedge and angle of osteotomy. The desired correction was calculated by adding the differences of humero-ulnar angle of both elbows and adding normal valgus of normal elbow (Fig. 21.3). The K wire was inserted parallel to propose osteotomy site one proximally and one distally. The osteotomy cut is obliquely from proximal/lateral to distal/medial just above the olecranon fossa and medial epicondyle to decrease the prominence of the lateral condyle. The medial cortex is left intact to serve as hinge for the lateral closure. If the decision has been made to correct only the varus, the medial cortex is left intact, and the osteotomy is completed medially if rotation and/or extension also are to be corrected. Percutaneous pins are placed from the lateral side to fix the osteotomy site. The arm is immobilized in a long arm cast in 90° of elbow flexion and forearm pronation for 6 weeks.



Fig. 21.3 Schema of lateral closing wedge osteotomy (LCWO) for cubitus varus. Angle of osteotomy is calculated by adding the differences of humero-ulnar angle of both elbows and adding normal valgus of normal elbow

A LCWO with K-wire fixation takes care of medial tilt, with minimal correction of the hyperextension component as well.

There are several advantages of the lateral closing wedge osteotomy: the dissection is subcutaneous and relatively safe, bone graft is not required, and stable fixation is achieved with simple Kirschner wire implants.

The more frequent limitations associated with LCWO are hypertrophic lateral scar, difficulty achieving secure fixation, loss of reduction and formation of a lateral spur. Ippolito et al. (1990) have reported 50% poor results in the long-term follow-up of LCWO, related to the loss of correction and recurrence of deformity. Furthermore, there is a tendency toward a prominence of lateral condyle that may compromise final cosmetic outcome; thus, a secondary serpentine deformity and lateral condylar prominence are potential and common complications.

There have been several modifications to the original technique with different results. The variables affecting a LCWO include the angle of osteotomy, the fixation methods, and the number of planes of deformity corrected (Papandrea and Waters 2000). *French osteotomy*, originally described in 1959 by French (1959), is a lateral closing wedge osteotomy through a posterior approach, leaving periosteal hinge medially, fixed with two screws and a figure-of-8 tension band wire between them on the lateral cortical surface (Bellemore et al. 1984).

Other techniques for correction of cubitus varus have been proposed.

King and Secor (1951) described a *medial opening wedge osteotomy (MOWO)*, which has the advantages of maintaining humeral length and better cosmesis through a medially based incision. In addition, the osteotomy does not produce a secondary translational deformity. Nonetheless a possible complication is an ulnar neuropraxia, due to the lengthening of the medial structures, and requires an anterior transposition of the ulnar nerve and a bone graft (Guner et al. 2013; Papandrea and Waters 2000).

Moreover, MOWO takes longer to heal, requiring long-term immobilization in cast.

Clinical experiences indicate that fracture healing times differ among patients of different age groups. For children with high healing capacity, union of a distal humeral osteotomy is achieved within 3 to 6 weeks, with a fast recovery of elbow function, while for adults, the union of the osteotomy in this region usually requires 3 months. In addition, children's elbow usually is not inclined to stiffness as those

of adults. The result may be unsatisfactory because of insufficient or subsequent loss of correction. Moreover, a lateral prominence of lateral condyle due to translation of the distal fragment is a frequent cause of a poor cosmetic result. Wong and Lee (1990) suggested lateral condylar prominence may remodel with time, while Ippolito et al. (1990), in a long-term follow-up of corrective osteotomy for cubitus varus, described persistence of this deformity at final follow-up. Levine et al. (1996) stressed the importance of medial displacement of the distal humerus during operative correction to decrease the prominence of the lateral condyle, but medial displacement disrupted the periosteum on the medial side leading to instability and difficulty with fixation.

Rehabilitation after operation to recover progressive range of motion in flexion and extension is useful overall for teaching to the little patients and his parents correct modalities of autotherapy.

21.5 Nonunion

Nonunion is a common complication of lateral condyle fractures. Beaty and Wood (1985) found a 28.5% of nonunion rate in fractures treated with a closed modality. Flynn (1989) established that nonunion occurs when the fracture had not united by 12 weeks, and delay union when a collar sign is present at 5 weeks. Nonunion of the medial humeral epicondyle was present in 55% of patients treated nonsurgically, but the functional results were good (Farsetti et al. 2001).

Radiographically, nonunion is best seen on the anteroposterior film as a high collar-like projection of the posterolateral metaphyseal fragment that is attached to the physis. The fracture edge of the metaphyseal fragment is blunted and shifted laterally, with a persistent fracture gap and little or no evidence of callus.

Nonunion of the lateral condyle can result in progressive *cubitus valgus deformity*, from proximal migration of the lateral condyle, weakness, loss of elbow motion, occasional pain, and tardy ulnar nerve palsy (Jacob et al. 1975). Cubitus valgus should also occur from premature closure of the capitellar physis.

Nonunion are at risk for progressive displacement, with the fragment migrating proximally, increasing valgus deformity and developing tardy ulnar nerve palsy.

The treatment for valgus deformity is indicated when the carrying angle is greater than 20°.

Several authors advocate nonoperative treatment because of the risk of loss range of motion and avascular necrosis postoperatively. In addition, many patients with long-term nonunion have no functional disability but only cosmetic deformity and sometimes ulnar nerve compression in adult patient. Other authors instead have obtained satisfactory results with the operative treatment of nonunion, advocated early surgery for established nonunion when the condylar fragment is in good position, while he advised against surgery when it is in poor position, because of the high risk of damage to the physeal plate of the fragment and secondary growth arrest leading to cubitus valgus. Storm et al. (2006) adopted the treatment with compressive screws across the metaphyseal portion in patients who have a simple, more recent nonunion, and minimal displacement. Bone grafting is rarely needed in these cases. In established nonunion, the fracture site needs to be explored in order to provide fresh cancellous surfaces for opposition. Supplemental bone grafting could be used if it remains a significant gap. The fixation must provide compression across the fracture site and enough stability to allow an early active motion. A postoperatively loss of motion can result and the extension is often limited about 10–15°. This does not interfere with functional abilities, but in some studies, the loss of motion was as high as 60%.

If a tardy ulnar palsy is present, anterior transposition of the ulnar nerve should be performed.

A simple angular osteotomy corrects the cubitus valgus, which is malalignment between the axes of the forearm and arm. This osteotomy is useless in the treatment of compound valgus from a type 2 fracture–dislocation. The unaesthetic appearance persists from a protuberant medial epicondyle if the valgus is treated by a closing wedge medial osteotomy. The osteotomy for proper correction requires lateral translation of the forearm and subsequent adduction of the distal fragment.

In conclusion nonsurgical treatment is appropriate for asymptomatic nonunion of the lateral condyle. Patients with asymptomatic nonunion, valgus deformity, and tardy ulnar nerve palsy should be treated with ulnar nerve transposition (Fig. 21.4). The treatment of established nonunion of the lateral condyle in symptomatic patients who have cubitus valgus is controversial. Surgery is not always successful and often leads to loss of motion. The general trend of surgical treatment is to use less invasive techniques.

21.6 Nerve Injuries

The incidence of acute neural injuries associated with supracondylar fractures has been estimated to be 10–20%, with a male preponderance (M:F = 3:2). The most frequently injured nerve is the radial nerve, with a reported incidence of injury about 16% with humeral fractures (Babal et al. 2010; Guner et al. 2013; Lins et al. 1999; *Beaty and Kasser* 2008).

Radial nerve injuries are usually associated with fractures in which the distal fragment is posteromedially displaced and penetrates the brachialis muscle laterally.

The median nerve injuries are associated with fractures in which the distal fragment is posterolaterally displaced. The median nerve crosses the elbow with the brachial artery.

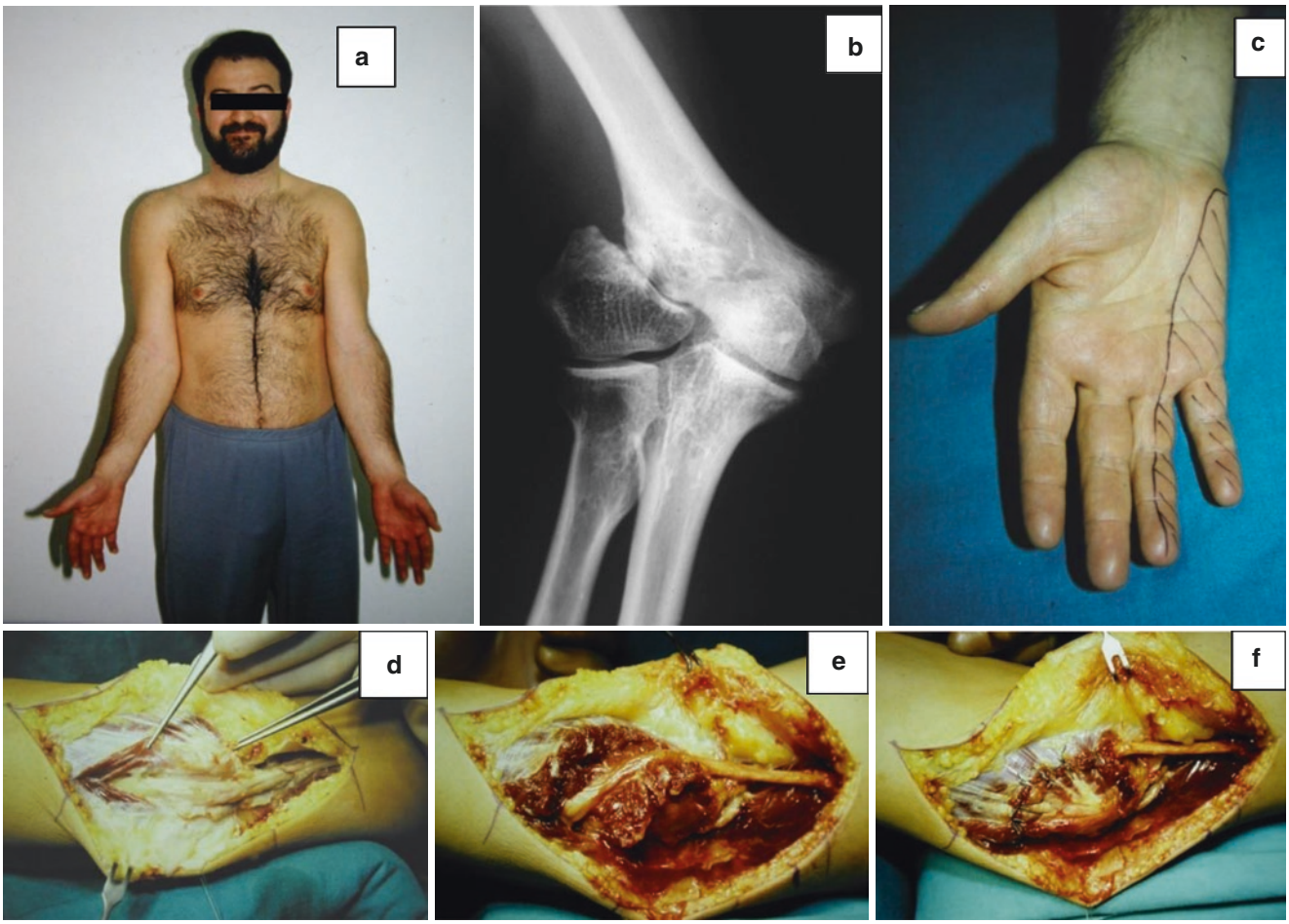


Fig. 21.4 *Ulnar nerve compression in progressive cubitus valgus sequel of lateral condyle* (**a**) G.R. 36 y good function of the elbow. (**b**) RX nonunion of lateral condyle fracture of 31 years ago, (**c**) sensitive deficit of ulnar nerve, (**d**) neurolysis of compressed ulnar nerve at the elbow, (**e**) epitrochlear muscle section, (**f**) intramuscular anteposition of the ulnar nerve

Posterolateral displacement of the fractured distal fragment results in anteromedial displacement of the proximal fragment that is driven against the brachialis and the median nerve. This can result in complete or more commonly partial median nerve neuropathy, in particular the anterior interosseous nerve.

The median nerve sometimes can be entrapped in the fracture callus during the healing. The anterior interosseous nerve contusion is the most common form of post-traumatic neuropathy, constituting approximately 50% of all nerve injuries with pediatric supracondylar fractures, and resulting in loss of flexor pollicis longus flexion.

The ulnar nerve is the least commonly injured nerve, and its palsies most frequently occur iatrogenically from repeated reduction maneuvers or during pinning internal fixation with Kirschner wires or with the flexion-type supracondylar fracture when the spike of the proximal fragment is directed posteriorly. Indeed, most nerve deficits associated with supracondylar fractures are neurapraxic injuries that resolve with observation within 3–5 months after the fracture. When the nerve injury is secondary to treatment, most of the authors agree which allow 3 weeks for the fracture to heal. If the nerve or nerves do not significantly improve during the further clinical course, a prompt revision of the nerve after an electromyography is recommended. Similarly, exploration should be considered for nerve deficits that persist beyond 4 months. When there is evidence of an initial motor and sensory deficit is indicated an initial open reduction with simultaneous repair of the affected nerve (Babal et al. 2010; Bado 1967; Beaty and Wood 1985; Bell Tawse 1965; Bellemore et al. 1984; Best and Ort 1994; Blount 1955; Bronfen et al. 2007; David-West et al. 2005; Derosa and Graziano 1988; Di Gennaro et al. 2015; Exner 2001; Farsetti et al. 2001; Flynn 1989; Fowles et al. 1983; French 1959; Gogola 2006; Guner et al. 2013).

Monteggia fractures or proximal ulna fractures with associated radial head dislocations commonly are associated with various nerve palsies. The most common of these is radial nerve (10%) and posterior interosseous nerve palsy (3–43%) (Guner et al. 2013).

Moreover, tardy ulnar nerve palsy can be seen secondary to lateral condyle nonunion, with subsequent valgus deformity. Miller and Reinus (2010) reported in approximately 47% of his patients with tardy ulnar nerve palsy a previous fracture of the lateral condylar physis in childhood. The onset of symptoms was gradual and varied from 30 to 40 years. In another study of 100 patients, the average interval of onset was 22 years. First motor loss occurred, followed by sensory deficiency. Various treatments have been proposed, such as anterior transposition of the ulnar nerve or release of the cubital tunnel.

21.7 Fishtail Deformity

Fishtail deformity of the distal humerus (coined by Wilson 1955) is a rare long-term complication of lateral condylar physeal fracture, due to premature closure of the central portion of the physis, or from osteonecrosis of the humeral trochlea (Wilson 1955; Yoo et al. 1992). The term describes the inverted U or V shape resulting from the continued growth of the medial and lateral portions of the physis.

The continued growth of the lateral or medial physis produces a sharp, wedge-shaped intercondylar notch that may impinge the proximal ulna and lead to diminished elbow motion. Toniolo and Wilkins (2008) described two types of fishtail deformity. The first one (type A) involves only the lateral portion of the medial crista at the apex of the trochlea and is seen most frequently after supracondylar fractures and lateral condylar fracture. The second type (type B) involves the entire trochlea and sometimes some portion of the medial metaphysic, and it could be seen after separation of the entire distal humeral epiphysis in older children or in medial condylar fractures.

Those patients with type A lesions are more likely to lose range of motion and develop degenerative joint disease, but do not develop angular deformities.

Type B lesions are more likely to create a progressive varus deformity, and occasionally, a late onset ulnar neuropathy.

Fishtail deformity is considered of little significance by many orthopedics. It is a deformity generally well tolerated in children. Recently there has been some concern over problems developing later in adulthood, including premature degenerative arthrosis, deformity, disability, and possible higher risk for intercondylar fracture. According to Gogola (2006), there is no primary treatment for avascular necrosis of the distal humeral epiphysis and no reports of physeal bar excision. If a partial physeal arrest is noted, future deformity may be minimized by surgical arrest of the remainder of the physis.

According to Bronfen et al. (2007), the key factor to predict disability, such as loss of motion, seems to be the amount of trochlea defect. Yang et al. (1998) proposed that the presence of longitudinal vascular channels in the epiphysis between the capitellum and trochlea may provide a hypothetical explanation for the fishtail deformity because there is little vascular communication between these two ossification centers. When any one of the vessels at this site is disrupted, necrosis of the segment of the epiphyseal cartilage may cause a fishtail deformity.

Descriptions of treatment options in the literature are limited. In addition to observation and nonoperative care, proposed treatment often includes arthroscopic or open debridement and loose body removal, capsulotomy, osteotomy or persistent deformity, or further surgery for recurrent mechanical symptoms.

21.8 Neglected Monteggia Lesion

A Monteggia lesion is an injury in which the radial head is dislocated in conjunction with a fracture or angulation of the ulna (Bado 1967). Forearm fractures are more easily recognized, but radial head dislocations are frequently missed, which may be attributable to difficulty in interpreting radiographs or insufficient radiographs that exclude the elbow joint up to 50% misdiagnosis or late diagnosis rate was found in literature.

The dislocated radial head may not be identified for some time after initial injury and after the healing of the ulna. Some confusion may occasionally arise in correlation with congenital dislocated radial head (the recently dislocated head of radius has a concave form, the head congenitally dislocated has a convex shape) (Letts et al. 1985). A late or missed Monteggia lesion is defined as one presenting 4 weeks after the initial treatment.

The late treatment of missed Monteggia lesion in the child remains controversial. The radial head may be left in its dislocated position or excised at maturity if pain or restriction of motion is present. Late reconstruction aims to reduce the dislocated head.

Chronic Monteggia lesion may present with progressive cubitus valgus, limited elbow flexion, limited forearm supination, overgrowth of the radial head, and pain with strenuous activity (Best and Ort 1994; David-West et al. 2005; Wilkins 2002).

For these injury most authors recommend corrective osteotomy of the ulna, reduction of the dislocated radial head with either repair or reconstruction of the annular ligament. The outcomes of these procedures are not predictable, and the potential complications are many: loss of elbow range of motion, persistent subluxation or redislocation of the radial head, osteolysis of the radial head, and delay or nonunion of the ulnar osteotomy or nerve injuries (Babal et al. 2010; Guner et al. 2013; Kim et al. 2002a; Kim et al. 2002b). The difficulty of obtaining a satisfactory function is directly proportional to the duration of missed dislocation.

If the interval between the injury and the time of the surgery is >6 months, the radial head has tendency to enlarge or overgrow, losing congruity with the capitellar articular surface. Some authors have commented on the deformity of the radial head at the time of delayed repair, and we concur that the changes in shape of the head can complicate the reduction and may require temporary use of a Kirschner wire to initially hold the reduction and take the stress of the annular ligament repair.

21.9 Indications for Treatment

Blount (1955) and Fowles et al. (1983) suggest that reconstruction provides the best results in patients who have had a dislocation for 3 or 6 months or less, respectively, but Fowles reported successful relocations up to 3 years after injury and Freedman up to 6 years after injury (Beaty and Kasser 2008).

The indications of treatment should be based on marked limitation of flexion and forearm motion and progressive cubitus valgus. Throughout the literature, the appropriate age seems to be younger than 12 years and that procedure not be performed if there is significant deformity of the radial head, flattening of the capitellum or valgus deformity of the neck of the radius.

Controversy exists in patient who is completely asymptomatic.

Treatment options are many, ranging from nonsurgical treatment to osteotomies and ligament reconstruction (Wilkins 2002).

A proximal ulnar osteotomy is performed in order to correct the angulation of the ulna, and some authors recommend osteotomy in situ of the deformity of the ulna. Ulnar elongation or shortening of the radius is advocated.

Several treatment options are available: corrective ulnar osteotomy, at side of original fracture or proximal, ulnar, and radial osteotomies, open or closed reduction of radial head, repair or reconstruction of the annular ligament, temporary fixation of the radial head with wire, or some combination of these techniques (Fig. 21.5).

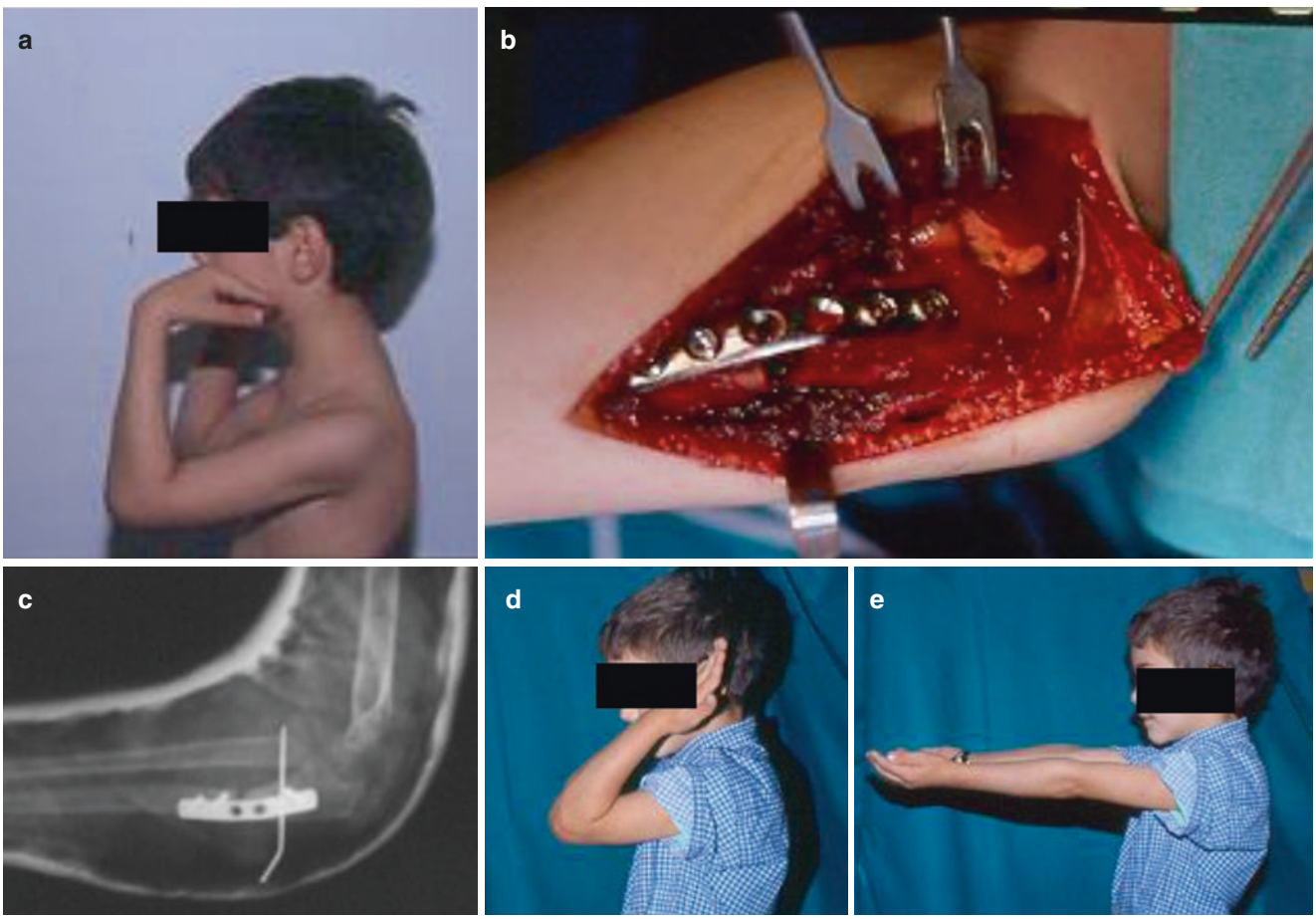


Fig. 21.5 T. S. 5-year-old *neglected Monteggia*. (**a**) Deficit of elbow flexion. (**b**) Ulnar osteotomy and synthesis with plate. (**c**) Reduction of radial head maintained by ulnoradial K wire. (**d**) Good elbow flexion. (**e**) Good elbow extension after 10 months

The ulna plays an important role in the deformity and in obtaining and maintaining reduction of the radial head through tightening the interosseous membrane.

The osteotomy with lengthening and angulation of the ulna, leading to radial head reduction, with or without the need to expose the radio-capitellar joint.

Osteotomy is indicated in a Monteggia lesion with a displaced ulnar fracture or in plastic deformation of the ulna, with the ulnar bow sign. Various types of osteotomies have been used to facilitate reduction of the radial head. Kalamki (1986) used a drill osteotomy, and allowing it to float, Hirayama used a 1 cm distraction osteotomy about 5 cm distal to the tip of the olecranon, and Mehta used a osteotomy of the proximal ulna and a bone graft to stabilize the osteotomy (Beaty and Kasser 2008).

There is no clear consensus on the requirement of annular ligament reconstruction to stabilize the radial head; some authors have reported its use only when there is residual instability of the radial head after ulna osteotomy (Bell Tawse 1965; Kim et al. 2002a; Kim et al. 2002b).

The most widely used method to reconstruct the annular ligament is to follow radial head reduction with the technique described by Bell Tawse (1965) using central slip of triceps tendon or lateral tendon strip (Lloyd-Roberts and Bucknill 1977; Stoll et al. 1992), with or without pinning radius to the ulna with Kirschner wire (Letts et al. 1985), or stabilization of the radial head reduced by a transarticular K wire (Bell Tawse 1965; Di Gennaro et al. 2015) to ensure reduction.

Postoperatively patients had elbow immobilized in an above elbow cast for 8–10 weeks with elbow in 90° flexion and full supination. After cast removal patients were referred for active and passive physiotherapy.

Radiographs are taken after cast removal and at follow-up to detect any residual subluxation and healing of the ulna osteotomy.

All children were reviewed at four-weekly intervals after cast removal for initial assessment of motion for 3 months and then at 3-month intervals to assess the find function.

Some authors have used gradual distraction with external fixator to effect radial head reduction without opening the joint (Di Gennaro et al. 2015; Exner 2001).

Conclusion

Sequels after traumatic injuries affecting a child's elbow are common due to underestimating the severity of the injury or neglected lesions as avoiding to recognize and to diagnose the type of fracture, inadequate or unstable fixation, a failure to reduce the articular fragments, prolonged postoperative immobilization, and the development of soft-tissue complications such as stiffness, peripheral nerve compression resulting in an early disability for the child, or tardy symptoms in the adult patient.

The possibility of spontaneous correction of defect results in the patient's age at the time of the trauma and type of lesion: the younger the patient is, the more rapid growth changes will be. The axial deviations in the main plane of motion of the body, the sagittal plane, are better corrected than deviations in the coronal plane. Post-traumatic deformities are caused either by residual axial deviations or by sequels of growth disturbances of the physis.

Indication to surgical treatment will be for patient with an important clinical and functional deficit after a precise evaluation of the lesion considering important rate of complications related in literature.

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Essex-Lopresti Lesions

22

Maurizio Fontana and Alessandra Colozza

22.1 Introduction

The first report of a forearm instability injury pattern is attributed to Curr and Coe (1946). However, Brockman (1931) had described this condition before that report. In 1951 Peter Essex-Lopresti (Fig. 22.1) described the proximal migration of the radius following the surgical excision of a comminuted radial head (RH) fracture. This migration generated a traumatic axial load from the wrist to the elbow, with distal radioulnar joint (DRUJ) disruption, rupture of the interosseous membrane (IOM), and RH fracture. Because of this detailed description, this injury pattern was assigned the eponym Essex-Lopresti lesion (Essex-Lopresti 1951). The literature defines "complex instability of the elbow" as lesions with articular elbow fractures associated with ruptures of the medial and lateral ligaments (Morrey 1997). In a previous work by the Authors we defined patterns of complex fractures of the forearm in which the fracture of one or both extraarticular bones is associated with dislocation of the DRUJ and the proximal radioulnar joint (PRUJ), or with wrist and elbow dislocation. In contrast, elbow or wrist dislocation associated with articular fractures was excluded from this definition (Celli et al. 2008). However, this definition has been successively superseded by later concepts. Nevertheless, the Essex-Lopresti lesion, like other traumatic patterns, can be classified in the category of unstable fractures of the forearm, which are characterized by the fracture of one or both intra-extraarticular bones, associated with instability of at least two of the three forearm constraints. The forearm constraints are the PRUJ, the DRUJ, and the IOM; these anatomo-functional structures constitute the forearm unit.

In the following chapter we review the anatomy and biomechanics of the forearm functional unit, the classifications of unstable fractures of the forearm, and Essex-Lopresti clinical-radiological assessments and surgical treatments.



Fig. 22.1 Peter Gordon Essex-Lopresti (1915–1951)

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22.2 The Forearm Unit: Anatomy and Biomechanics

The forearm can be considered as a single articulating joint where the interdependence of the different anatomical structures allows forearm rotation and elbow and wrist motion (Schemitsch and Richards 1992; Stewart 2007). All of these functions, especially pronosupination, explain the complex integrated relationship between the bones and soft tissue along the entire length of the forearm.

An understanding of the biomechanics of the forearm is essential for the acute management of unstable fractures and also for the management of late reconstruction. The elbow is represented by a triarticular joint (humeroulnar, humeroradial, and proximal radioulnar joints) (Soubeyrand et al. 2007). In elbow-forearm kinetics we must consider the flexor-extensor and pronosupination ligamentous stabilizers. The lateral ulnar collateral and medial collateral ligaments stabilize the elbow in flexion-extension; the annular square IOM and triangular ligaments control forearm pronosupination. The annular and denuce square ligaments are the intraarticular stabilizers of the PRUJ (Fig. 22.2). The IOM is an extraarticular complex stabilizer of the midportion of the forearm unit (Fig. 22.3). Our previous anatomic study describes five ligamentous components of the IOM (proximal oblique Weitbrecht cord, dorsal oblique accessory cord, central band [CB], accessory band, and distal oblique bundle) (Celli et al. 2008). The two proximal ligaments (proximal oblique cord and dorsal oblique accessory cord) prevent RH anterior dislocation (Celli et al. 2008) and are substantially longer than the three distal ligaments (central band, accessory band, and distal oblique bundle) (Moritomo et al. 2009). All these ligaments are isometric because the ulnar attachments are located almost on the axis of forearm rotation. The CB is the most important part of the IOM: it is approximately 17 mm × 10.6 cm in size and its mechanical resistance (13.1 ± 3.0 N/mm) is greater than that of the other parts of the membrane. Its modulus is 608.1 ± 160.2 mPa. Its elongation at breaking-point is 9.0 ± 2.0% (Pfaeffle et al. 1996). Histologically, the CB consists of 84% collagen; a structure half way between membrane and ligament. The CB arises from the inner ridge of the radial diaphysis (about

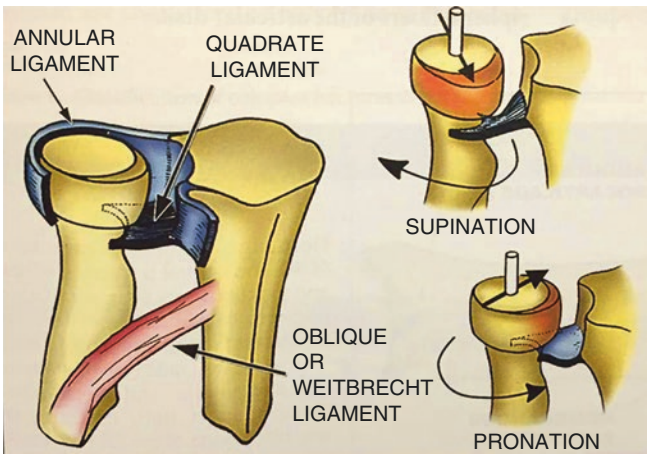


Fig. 22.2 The distal radioulnar joint (DRUJ) is stabilized by two articular ligaments: the annular and the quadrate. The quadrate ligament increases the joint stability, limiting anterior radius translation with the anterior fibers during supination and posterior translation with the posterior fibers during pronation (from Celli et al. (2008) with permission)



Fig. 22.3 The interosseous membrane (IOM) ligament. Early anatomic studies describe five ligamentous components of the IOM (proximal oblique Weitbrecht cord (*1*), dorsal oblique accessory cord (*2*), central band (CB) (*4*), accessory bands (*3*, *5*), and distal oblique bundle (*6*). The two proximal ligamentous components (proximal oblique cord and dorsal oblique accessory cord) prevent radial head (RH) anterior dislocation and are substantially longer than the three distal components (CB, accessory band, and distal oblique bundle). These components are isometric because the ulnar attachments are located almost on the axis of forearm rotation. The CB is the most important part of the IOM. The distal oblique bundle (present in 40% of human subjects) arises from the inner part of the distal ulnar diaphysis and runs, with opposite obliquity to the CB, to the ulnar side of the radial metaphysis. It may contribute to stabilizing the distal radioulnar joint and contrasts longitudinal shortening of the ulna

7.7 cm from the RH) and runs to the third middle-distal junction of the ulna (13.2 cm from the tip of the olecranon) (Chandler et al. 2003) with an oblique angle of 20–25° at the ulnar axis. The distal oblique bundle (present in 40% of human subjects) arises from the inner part of the distal ulnar diaphysis and runs, with an oblique angle opposite in direction to that of the CB, to the ulnar side of the radial metaphysis. It may contribute to the stability of the DRUJ (Moritomo et al. 2009) and contrasts longitudinal shortening of the ulna. The triangular fibrocartilage (TFC) is an intrarticular suspensor ligament of the DRUJ (Fig. 22.4).

Many studies have shown the ability of the IOM and the TFC at the DRUJ to maintain axial forearm stability. After RH excision, the IOM provides stability for 71% and the TFC for 8% of the total. Only when both the IOM and the TFC are disrupted a significant proximal migration of the radius occur. These forearm ligaments have two functions: to *stabilize* the two forearm bones *transversally* and *longitudinally* by transferring loads from the radius to the ulna. The radius and ulna are roughly parallel are and connected at each end by a well-constrained joint and at the mid-portion by the IOM. The system is relatively tight and it is difficult to injure one of these structures without affecting another part of the system.

The ulna is a relatively straight bone, but the radius is much more complex in shape. Sage (1959) pointed out the complexity of the angles and curve in the radial bone). The radius has four small but consistent curves: two on the frontal plane (about 13° proximally and 6° at mid-shaft) and two in the sagittal plane (about 13° proximally and 9° at mid-shaft). The curves of the radius give it the distinct radial bow necessary for it to cross over the ulna in pronation, while at the same time maintaining relative tension in the distal portion of the IOM in all positions. Schemlitsch and Richards (1992) confirmed the importance of restoration of the radial bow to forearm function after fracture. The patient may not be able to achieve full pronation and good grip strength after fracture malunion if the radial curve is not recovered. The ulna is essentially fixed by the proximal anatomy (ulnohumeral joint), and the radius at the radiocarpal unit draws in the space a simple cone, with its axis running roughly from the center of the RH to the center of the distal part of the ulna. The normal range of motion has been described as 71–75° for pronation and 82–84° for supination. Two conditions must be present to allow free and full pronosupination movement: (1) the radius and ulna must be of equal length, with normal location and amount of radial bow and (2), there must be a stable relationship between the radius and ulna at the PRUJ, middle radioulnar joint, and DRUJ.

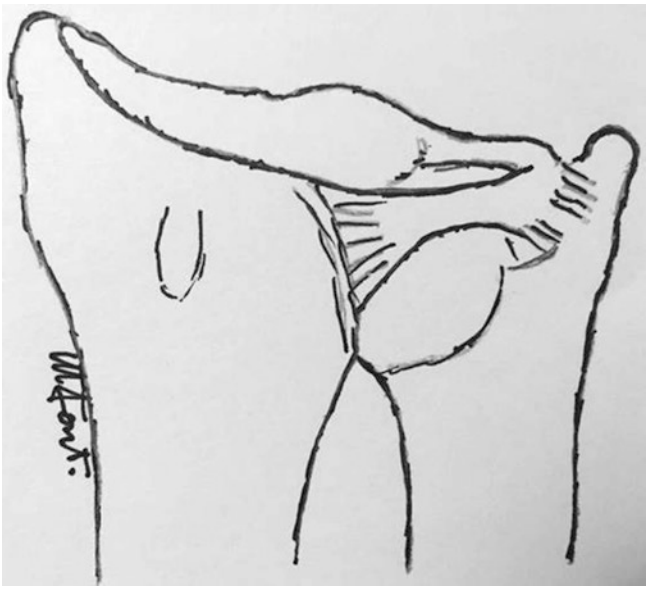
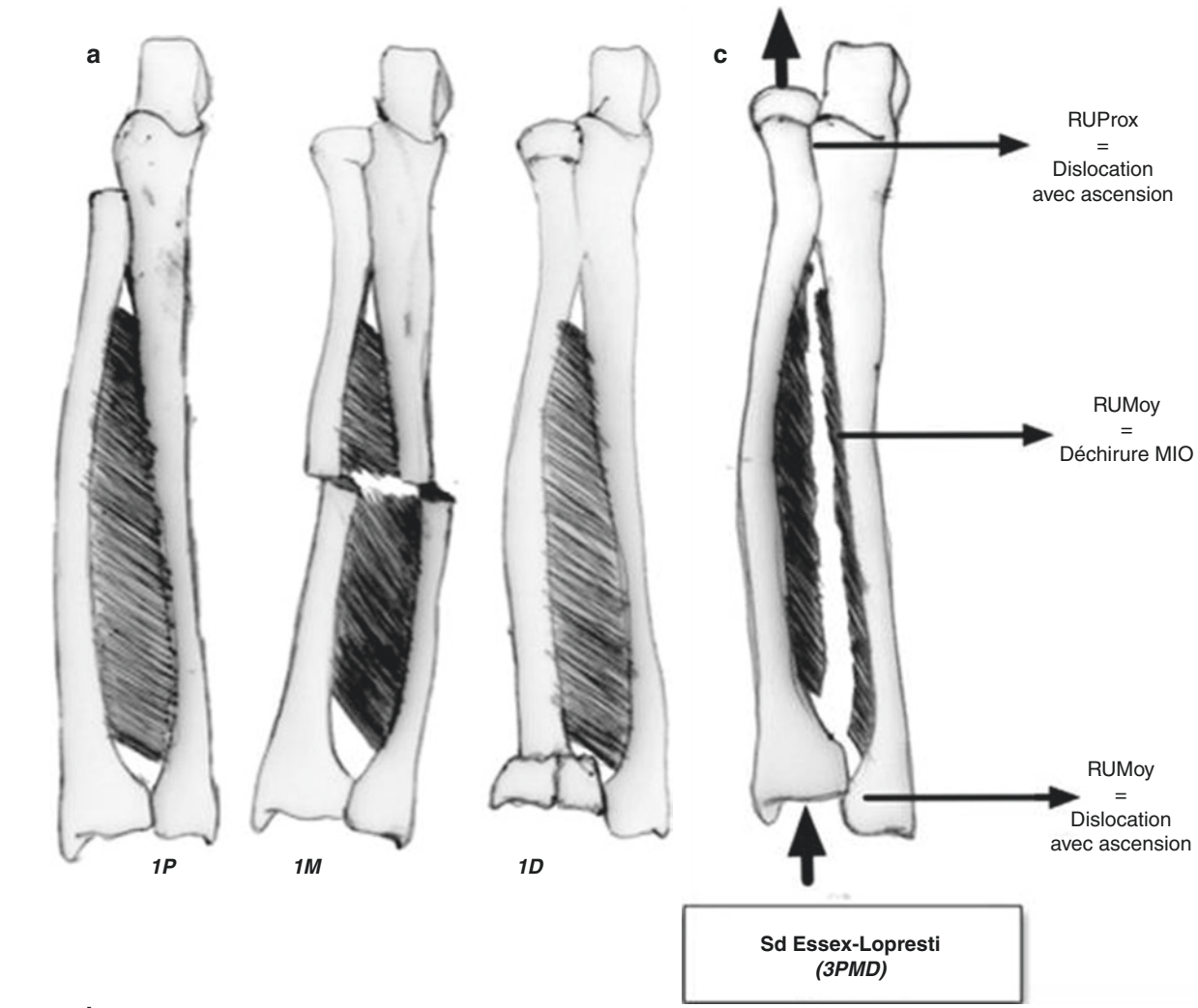


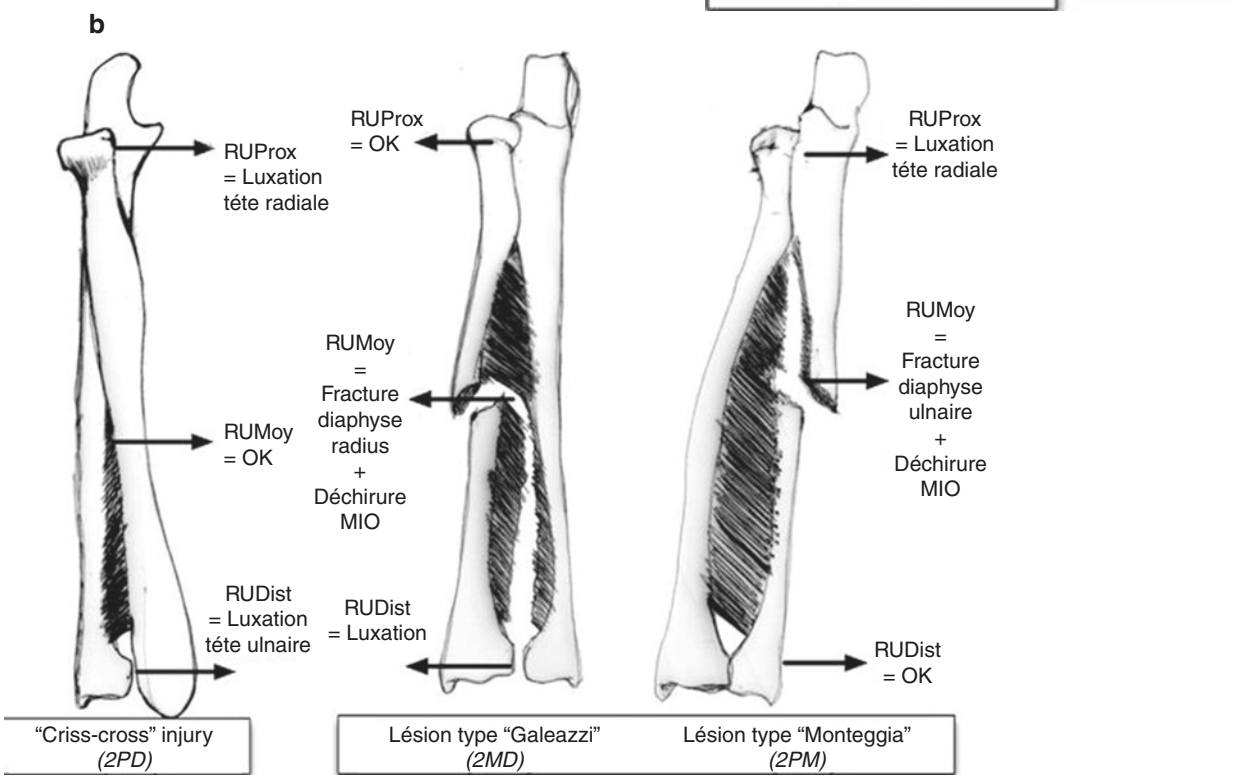
Fig. 22.4 The triangular fibrocartilage (TFC) is an intraarticular suspensor ligament of the DRUJ. It is trangular in shape and 1–2 mm thick at its base. The biconcave body of the structure stretches across the ulnar articular dome, and its apex is attached to the head concavity and projecting ulnar styloid

22.3 Classification of Unstable Fractures of the Forearm

In 2007 Soubeyrand et al. (2007) proposed the "three forearm constraints" concept. The forearm unit has to be regarded as an association of three constraints: the PRUJ, the middle constraint (IOM), and the DRUJ. Each constraint is important for the stability and movement of the forearm. If we have a *one-constraint* disruption (distal radius fracture, simple RH fracture, synostosis) there is a decrease in pronosupination without instability *(stage 1)*. If we have a *two-constraint* loss this is a *stage 2* partial transverse instability (criss-cross, Galeazzi, or Monteggia lesions). If *three constraints* are destroyed this is a *stage 3* longitudinal-transverse instability (Essex-Lopresti lesion). Stage-2 and -3 patterns (criss-cross, Galeazzi, Monteggia, and Essex Lopresti lesions) are categorized as unstable fractures of the forearm (Fig. 22.5).

The lack of the three constraints (triangular cartilages of the DRUJ and IOM and the RH of the PRUJ) can lead to two injury patterns: *acute or chronic Essex-Lopresti lesions*. The creation of these pathologies depends on the IOM response to the trauma: an immediate proximal translation of >5 mm associated with a pluri-fragmented RH fracture is indicative of an acute complete IOM laceration that is irreparable. Progressive radial migration after RH resection (>4 weeks) or painful RH prostheses with DRUJ instability and discomfort and grip weakness demonstrate a partial IOM tear that


a
1P
1M
1D
c
RUProx
=
Dislocation
avec ascension
RUMoy
=
Déchirure MIO
RUMoy
=
Dislocation
avec ascension
Sd Essex-Lopresti
(3PMD)


b
RUProx
= Luxation
téte radiale
RUMoy
= OK
RUDist
= Luxation
téte ulnaire
"Criss-cross" injury
(2PD)
RUProx
= OK
RUMoy
=
Fracture
diaphyse
radius
+
Déchirure
MIO
RUDist
= Luxation
Lésion type "Galeazzi"
(2MD)
RUProx
= Luxation
téte radiale
RUMoy
=
Fracture
diaphyse
ulnaire
+
Déchirure
MIO
RUDist
= OK
Lésion type "Monteggia"
(2PM)

becomes complete after repetitive traction by the biceps brachii (Fig. 22.6) a pattern described as a missed Essex-Lopresti lesion (Shepard et al. 2001; Hotchkiss et al. 1989; Van Riet and Morrey 2010).

The missed Essex-Lopresti pattern was hypothesized by Jungbluth et al. (2008). This hypothesis opened a new field of discussion around the early loosening of and/or painful RH prostheses. In 2006 Pfaeffle et al. (2006) wrote: "Ligamentoplasty decreases the load applied by prostheses to the capitellum". Duckworth et al. (2014) reported that 28% of RH prostheses had loosened 6 years after the operation. It is possible that the loosening of RH prostheses or RH pain may be caused by *forearm microinstability*. Some authors; for example, Soubeyrand et al. (2007), Jungbluth et al. (2008), Pfaeffle et al. (2006), and Marcotte and Ostermann (2007) recommend a ligamentoplasty in patients with acute or chronic longitudinal instability of the forearm.

Some acute and chronic Essex-Lopresti lesions could require an IOM reconstruction to correct macro-deformities and instability (ulnar and DRUJ instability, radial migration at the PRUJ) or micro-deformities and progressive instabilities (painful RH reconstruction or substitution, capitulum humeri cartilage erosion, and wrist discomfort).



Fig. 22.6 The missed Essex-Lopresti lesion. A partial IOM tear can become progressive even in presence of an RH prosthesis. Such a tear leads to clinical forearm microinstability that damages the capitulum humerus cartilage and causes RH overload and potential stem loosening. Classic radial elbow pain then arises, especially seen in blue collar workers using vibrating machinery. An RH exploration/excision and IOM plasty can solve the problem (drawing by Marc Soubeyrand: personal communication. With permission)

22.4 Essex-Lopresti Clinical-Radiological Assessments and Surgical Treatments

The appropriate treatment of Essex-Lopresti lesions requires an understanding of the biomechanics of forearm stability and early diagnosis for both acute and chronic lesions. When the patient presents with a comminuted RH fracture, the chance of acute or chronic development of an Essex-Lopresti lesion must be considered. Trousdale (1992) described 20 cases of Essex-Lopresti lesions, defining the lesion as a longitudinal radioulnar dissociation. In the French literature, Soubeyrand et al. (2007) reported that Essex-Lopresti lesions compromised the stability of the entire forearm unit in two planes, mainly longitudinal but also transverse.

22.4.1 Clinical Assessment

Disruption of the IOM is easily missed in patients with an Essex-Lopresti lesion. None of the imaging techniques available for diagnosing disruption of the IOM are completely dependable. History and physical examination are essential for diagnosing an Essex-Lopresti lesion. Patients have a history of intense axial load to the forearm. The patients are mainly male, blue-collar workers or athletes (cyclists, bikers) where the fall down is uncommon and at high energy.

The most common symptoms reported by patients with primary or secondary forearm longitudinal instability are: (1) pain in the posterior aspect of the wrist (increased with forearm supination) and in the elbow when the proximal

Fig. 22.5 (**a**–**c**) The triarticular forearm unit and its trauma classification. The forearm has to be considered as a functional unit, with its components connected dynamically by the proximal radioulnar joint (PRUJ)-IOM-DRUJ. The Soubeyrand alphanumeric classification highlights the number of disrupted constraints and the anatomic seat (proximal-median-distal). If we have a one-constraint loss (**a**) this a stage 1 lesion. If we have a two-constraint loss this is stage 2: partial transverse instability (criss-cross, Galeazzi, and Monteggia lesions (**b**). If three constraints are destroyed this is stage 3 longitudinal-transverse instability (Essex-Lopresti (**c**). Stage-2 and -3 patterns (criss-cross, Galeazzi, Monteggia, and Essex-Lopresti lesions) are categorized as unstable fractures of the forearm. Drawings from Soubeyrand et al. (2007), with permission from the authors

stumps of the radius abut the capitellum; (2) loss of range of motion in forearm supination and wrist extension; (3) evidence of posterior prominence of the distal ulna at the wrist (fixed subluxation); (4) hand grip and pronation weakness and forearm discomfort, especially on palpation; and (5) associated elbow valgus apprehension because of instability.

The clinical evaluation starts from tests of elbow stability: many patients with an Essex-Lopresti lesion present with a lateral ulnar or medial collateral ligament-associated tear. The drawer, pivot shift, and valgus and varus pronation tests (also fluoroscopy-assisted) are the commonest maneuvers to perform.

In acute lesions, IOM palpation is difficult because of the patient's pain reaction and this reaction is already suspicious for diagnosis. In chronic lesions we suggest the "C-fingers" comparative test: the arm is placed on a table, with the elbow flexed at 90°, and the forearm vertical to the floor plane. With the thumb opposing the other fingers (like the letter "C") we squeeze the forearm and apply pressure to the dorsal-volar surface to feel muscular-IOM resistance in pronation and supination; the test must be comparative and is contraindicated when there is muscular hypertrophy and edema. We check the IOM for third middle (CB) and distal (dorsal oblique band) segment tenderness. Resistance of one or more segments is suspicious of partial or complete IOM tear (Fig. 22.7).

After forearm exploration it is mandatory to evaluate DRUJ stability. Forearm rotation decreases because the distal ulna loses its position in the sigmoid notch of the radius and becomes subluxed in more dorsal and distal positions; in addition, wrist extension is blocked because the distal ulna impinges against the dorsal carpus. At the wrist, the physician will test the DRUJ with dorsal-volar comparative translation of the ulna in neutral, supination, and pronation positions.

22.4.2 Imaging

Proximal translation of the radius of 2 mm occurs without clinical symptoms in most patients after RH excision. However, once the radius is translated more than 10 mm, functional impairment occurs. The following imaging studies are used:

- X-ray views, for which true posteroanterior and lateral radiographs of the elbow and wrist, and grip views of both wrists, are mandatory. Grip views can be helpful in detecting dynamic radial shortening, which is a change in ulnar variance with active use of the forearm. To obtain a grip view series, radiographs of both wrists are done with the forearm positioned in pronation and the X-ray beam directed 15° proximally and centered on the DRUJ. Both wrists are then imaged in the same pronated position while the patient grips a dynamometer at 20 kg.
- Dynamic fluoroscopic evaluation, which demonstrates the possibility of correcting forearm longitudinal instability with axial traction.
- Ultrasound comparative and dynamic studies, which are less expensive than magnetic resonance imaging (MRI), can usually be performed quickly, and allow for the dynamic evaluation of the IOM.
- MRI, which assesses the static anatomic status of the IOM and depicts tears, although there are often artifacts because of previous trauma (in acute lesions) or surgical procedures (in chronic lesions).

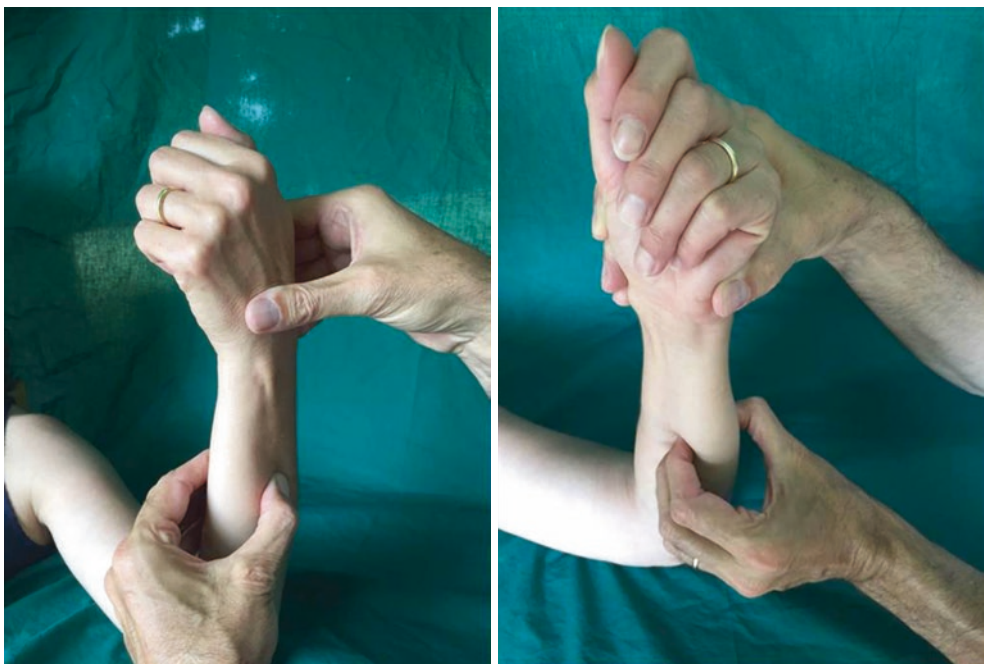


Fig. 22.7 "C-fingers" test. This is an easy preoperative comparative maneuver to test IOM resistance. We suggest this be used mainly for chronic cases without edema and anesthesia: the arm is placed on a table (as shown in the images). With the thumb opposing the other fingers (like the letter "C") we squeeze the forearm and apply pressure to the dorsal volar surface to feel muscular-IOM resistance in pronation and supination. We check the third medium segment, the CB, and the distal segment (dorsal oblique band) of the IOM for tenderness. Resistance of one or more segments is suspicious for partial or complete IOM tear

22.4.3 Longitudinal-Transverse Instability Maneuvers

The following maneuvers are used:

- The axial stress test (Davidson et al. 1993). Manual traction is done preoperatively under anesthesia applied through the hand and wrist. With the forearm in the supine position, the shoulder is abducted at 90° and internally rotated, the elbow is bent to 90°, and the forearm is held in neutral rotation. Longitudinal traction is applied and C-arm shows the wrist and elbow for lateral comparative views before and after traction. Distal radial migration of 5 mm must be considered indicative of instability.
- The "muscular hernia sign" (Soubeyrand et al. 2006). Under dorsal ultrasound examination anteroposterior pressure is applied to the anterior side of the forearm (preoperatively, under anesthesia). If the interosseous ligament is torn, the volar muscles pass through the disrupted IOM. The test must be done at the level of the CB and dorsal oblique band (when present) to evaluate potential proximal radial migration and translation in shortening osteotomy of the ulna.
- Radius pull test (Smith et al. 2002). This is an intraoperative test that has been described in cadaver models with excision of the RH and sectioning of the IOM and the TFC complex (TFCC). The pull test is positive when there is ≥3 mm of proximal radial migration; migration of 6 mm or more is observed in gross instability of the forearm with injuries of the IOM and the TFCC.
- Intraoperative radius joystick test (Soubeyrand et al. 2011). This a maneuver to test the longitudinal-tranverse stability of the forearm during surgery for fracture of the RH. The procedure is similar to that of Smith et al. (2002) described above. The forearm is placed in maximal pronation and the arm is held firmly to immobilize the humerus. A clamp is placed on the radial neck and pulled laterally, using moderate force. The test is positive if the proximal radius moves laterally. The test is negative if the radius remains immobile (positive predictive value 90%, negative predictive value 100%). Our preoperative assessment protocol is as follows: (1) for elbow stability, IOM "C-fingers" test; (2) fluoroscopic-ultrasound dynamic forearm evaluation (axial stress test; muscular hernia sign); and (3) comparative dynamic DRUJ stress test. Our intraoperative assessment protocol consists of: (1) the radius pull test and (2) the radius joystick test.

These maneuvers are highly sensitive for acute lesions and they provide useful information in acute-chronic lesions regarding the possibility of correcting forearm longitudinal-transverse instability with RH replacement, ulnar shortening osteotomies, and IOM-DRUJ plasties.

22.4.3.1 Surgical Options

Early diagnosis of Essex-Lopresti injuries is mandatory because acute injuries seem to have better outcomes than chronic ones. The aim of surgical treatment is to restore the triarticular forearm relationship by:

- Restoring bone length;
- Reconstructing the CB; and
- Stabilizing the DRUJ and PRUJ.

In Essex-Lopresti injuries, proximal radial migration is approximately 5 mm in the acute pattern and 10 mm in the chronic pattern. In the acute pattern, bone length equalization is important throughout the RH reconstruction or substitution procedure, as is checking for DRUJ reduction. In the chronic pattern we always suggest ulnar shortening; RH prostheses are applied when the cartilage of the capitulum of the humerus is free and longitudinal forearm instability is corrected.

22.4.3.2 6.1.1. Reconstruction Techniques

Multiple techniques have been described for reconstruction of the CB of the IOM. Marcotte and Osterman (2007) proposed an algorithm for the management of acute and chronic instabilities of the forearm. They note that IOM reconstruction is allowed in both acute and chronic lesions and also in the presence of RH prostheses. They originally used a bone-patellar tendon-bone autograft for the CB and plasty for chronic cases. This procedure is currently performed using bone-ligament-bone allografts, thus eliminating donor-site morbidity. Various tendon grafts or synthetic devices have been used for forearm stability. One study included the use of the palmaris longus or half of the flexor carpi radialis tendon; however, this method does not provide adequate strength for reconstruction of the CB (Stahen et al. 1997). An Achilles tendon allograft restores approximately 50% of the transferring forces of the native IOM (Tomaino et al. 2003). Sellman et al. (1995) and Sabo and Watts (2012) further demonstrated the use of nylon rope to perform a flexible CB reconstruction and found that the construct restored stiffness, but this occurred only when the radiocapitellar articulation was restored. Of note, Kuzma (2003) described the clinical use of pronator teres transfer to reconstruct the CB.

After some initial experience with tibialis posterior grafts, we do not use allografts now because of the risk of host reaction and, in contrast to intrarticular ligamentous reconstructions, there is no tendon synovialization. Furthermore, tendons require a precisely measured length and a large tunnel, which can weaken the ulna. We use a #2 Ethibond nonabsorbable braid passing through a 1.5-mm radioulnar tunnel; other devices Ethibond (Ethicon, NJ, USA), Ultratape (Smith&Nephew, UK), Fiber-wire (Arthrex, FL, USA), and LARS (LARS, France) are also effective, but more expensive. Fixation may be done with miniplates or titanium interference screws.

22.4.3.3 6.1.2. Plasty Techniques

IOM plasty. The characteristics of IOM plasty techniques are: (1) ligamentoplasty has to stabilize the forearm longitudinally (other procedures allow transverse stabilization); (2) the plasty has to be isometric during pronosupination; (3) the technique has to be reproducible and safe, preventing neurovascular injury; and (4) grafts must be of the correct length and straight resistance.

DRUJ plasty. This plasty is mandatory when comparative dorsal-volar subluxation is evident. In chronic lesions arthroscopic debridement allows better equalization with the radius. Many sophisticated open or scopic techniques are available but, in such challenging surgery, an easier procedure is preferred. In a really unstable DRUJ, during the three times surgery, we suggest transient pinning to control the exact forearm length.

PRUJ plasty. In regard to this plasty for our cases, we did not find proximal stabilization to be necessary for simple Essex-Lopresti lesions, and our search of the literature showed no such procedures for these lesions. In our practice, we use a radial loop plasty, usually with an autologous triceps strip fascia, in very unstable transverse forearm instability complicated by ulnar or radial malunion (Fig. 22.11a–g).

We agree with the distinction made between acute and chronic Essex-Lopresti lesions and we recommend accurate preoperative evaluation and imaging, to be performed mainly under anesthesia.

22.4.3.4 6.1.3. Acute Essex-Lopresti Lesions (<4 weeks)

- Elbow ligament reconstruction. On fluoroscopy-assisted stability tests, a lateral ulnar collateral ligament or a medial collateral ligament is frequently evidenced. We suggest the suturing of all ligaments when an RH prosthesis is implanted. Elbow instability produces dangerous movements, such as drawer and pivot shifting, that may cause humeral chondral abrasion of the prosthesis.
- RH reconstruction or substitution. If RH fragmentation does not allow a stable synthesis, the prosthetic head must be placed line-to-line to the ulnar sigmoid notch. The Kocher approach is our preferred method. Controversial results for RH prostheses have led to the idea that residual forearm longitudinal microinstability, stabilized by plasty, resulted in pain-free press fit stem loosening. In patients who were blue collar workers we noted stable, indolent, full elbow-forearm-wrist motion with progressive proximal radial neck reabsorption (Moon et al. 2000). In the series reported by O'Driscoll there was physiological evolution of bone-tip ingrowth. Some companies have introducing macroporous straight stems. On the other hand, loose-fit stem prostheses are useful devices.
- IOM plasty. Marcotte and Ostermann (2007) did not use their technique in acute cases. Our preferred method is similar to the procedure of Soubeyrand et al. (2007): in correspondence of the maximum radial bow and in the opposite part of inner ridge under brilliance, a 5-cm incision is made. Crossing between flexor-extensor muscles, the distal RH of the pronator teres is recognized. At intermediate forearm rotation a 1.5-mm drill is used on the distal ulnar neck, with a 20° axis with respect to the longitudinal forearm axis. The stabilizer device (autoallograft, artificial) crosses the forearm bones dorsally under the muscular extensor compartment. We suggest the use of a ligament passer, such as that used in knee surgery. Under C-arm view the stabilizer device is stretched, pronosupination and RH position is checked, and the device? is definitively fixed. Using #2 Ethibond braid, we fix the neoligament with a two-hole stainless-steel finger plate with three wires tied by itself; if necessary it is possible to loosen the knot and retie it.
- DRUJ Plasty. If the Distal Oblique Band ligament is intact, a surgical procedure is not mandatory. In DRUJ instability, double parallel pinning (wrist in full supination) is recommended; we suggest 3–4 weeks for quick restoration of motion (Figs. 22.8, 22.9, and 22.10).



Fig. 22.8 Case no.1. Acute Essex-Lopresti lesion. C.M., a male 42-year-old truck driver, sustained trauma in a car accident. He was right forearm-dominant and had a nickel chrome allergy. Note the four large unreconstructible fragments and two-constraint disruption (DRUJ and PRUJ). Proximal radial translation was 9 mm. Radial migration may be understimated if there is associated dorsal DRUJ subluxation

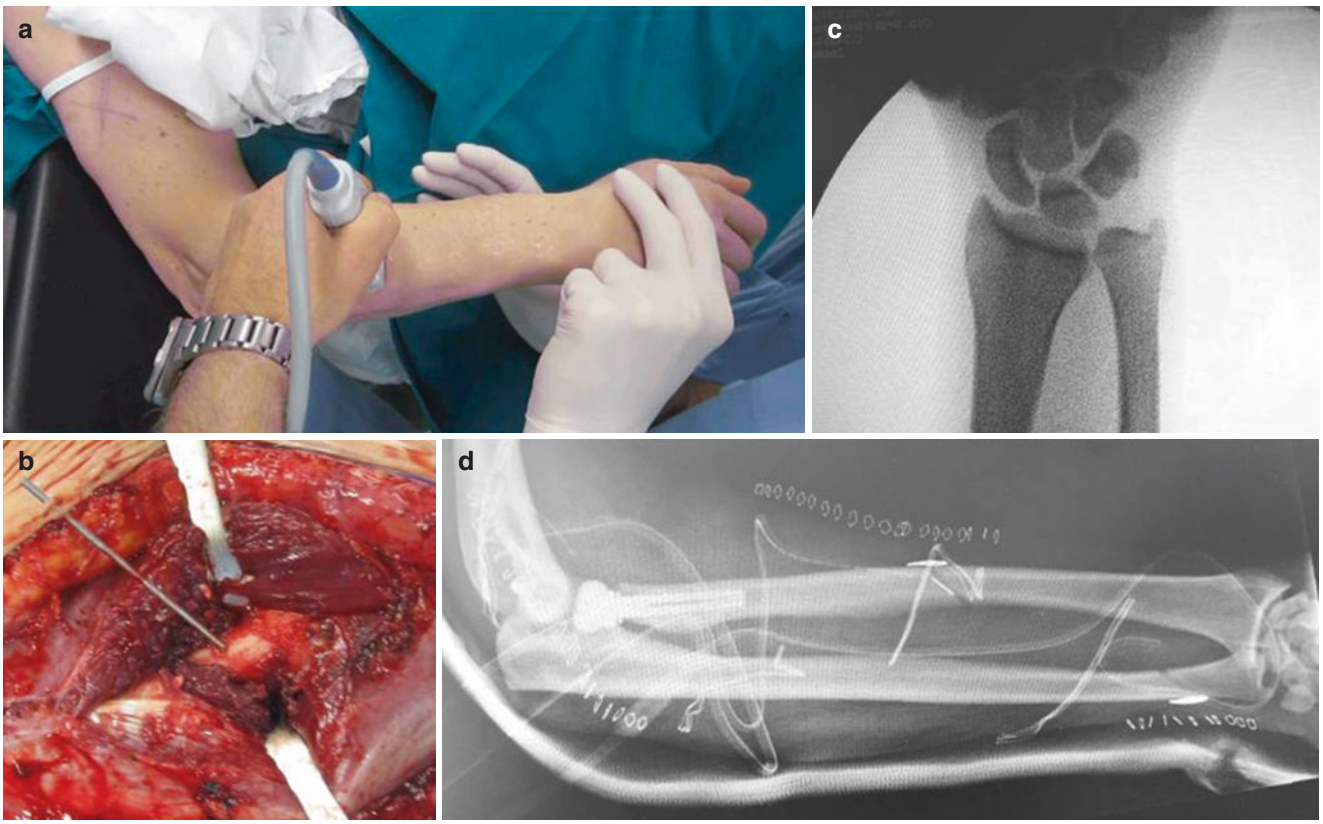


Fig. 22.9 (**a**–**d**) Preoperative axial stress test under anesthesia; the muscular hernia sign was positive and the DRUJ was unstable (**a**). A pyrocarbon RH prostheses was applied and a 2# Ethibond braid (Ethicon, NJ, USA) was passed through two isometric tunnels (the radial landmark is distal to the pronator teres tendon) and tied onto two miniplates (titanium plates or stainless steel plates) (**b**). The tension of the new ligament was checked in forearm pronosupination and by RH postioning (**c**). The lateral ulnar collateral ligament was sutured. A 3-mm plus ulnaris persisted: we decided not to do DRUJ pinning (a suspension cast was used for only 2 days) for quick motion recovery. Final X-ray control (**d**)

22.4.3.5 6.1.4. Chronic Essex-Lopresti Lesion (>4 weeks)

- The surgical options for this condition depend on reducing the ulnar variance at the wrist from positive to neutral (longitudinal instability); the time from trauma; and DRUJ stability (transverse instability).
- Elbow ligament reconstruction. Frequently the lateral compartment can be reconstructed with epicondylar augmentation. The medial ligament must be reconstructed with a graft if the RH is replaced but not if the RH is left in place.
- RH prosthesis. In patients who have had a previous Kaplan approach to the elbow, posterior radial branch isolation or electrostimulation is suggested. If a prosthesis is used, the implantation is performed by the classic procedure. However, prosthesization is not mandatory in an unstable elbow: calculated ulnar shortening, IOM reconstruction, and DRUJ plasty can support forearm tension without the need for a new RH.
- Shortening osteotomy of the ulna. We always suggest an ulnar shortening osteotomy to decrease the compartment tensions. The osteotomy length is calculated based on residual ulnar variance after RH prosthesis implantation or based on compressive bone length discrepancy after an axial stress test. The procedure starts from the third medium diaphysis. First the ulnar tunnel is prepared for ligamentoplasty, then the calculated bone cylinder is resected and compression osteosynthesis is performed with a plate.
- IOM Plasty. In chronic cases, ligamentoplasty is clearly recommended. The surgical procedure is the same as that for acute lesions?. For the correct planning of osteotomy and IOM plasty we suggest temporary DRUJ pinning.
- DRUJ Plasty. Many sophisticated DRUJ plasty techniques have been described, both open and arthroscopic. In Essex-Lopresti lesions we use the Fulkerson-Watson technique, a very simple and quick procedure that uses a tendon autograft or homograft such as a loop around the ulnar neck (Purisha et al. 2011). One or two 2.4mm anchors at the ulnar surface of the radial metaphysis will fix the loop (Fig. 22.11a–g).
- Other procedures. The Darrach, Sauve-Kapandji, and synostosis (Allende and Allende 2004) procedures are utilized as rescue techniques.



Fig. 22.10 (**a**, **b**) Clinical-radiological follow-up at 12 months. The patient had no pain and had returned to his previous work. He showed good DRUJ stability. Note the 30° supination limit, probably owing to incomplete isometricity of the tunnels and ligament. Radiologically, the 3-mm plus ulnaris remained. The Mayo Elbow Performance Index (MEPI) was 85/100

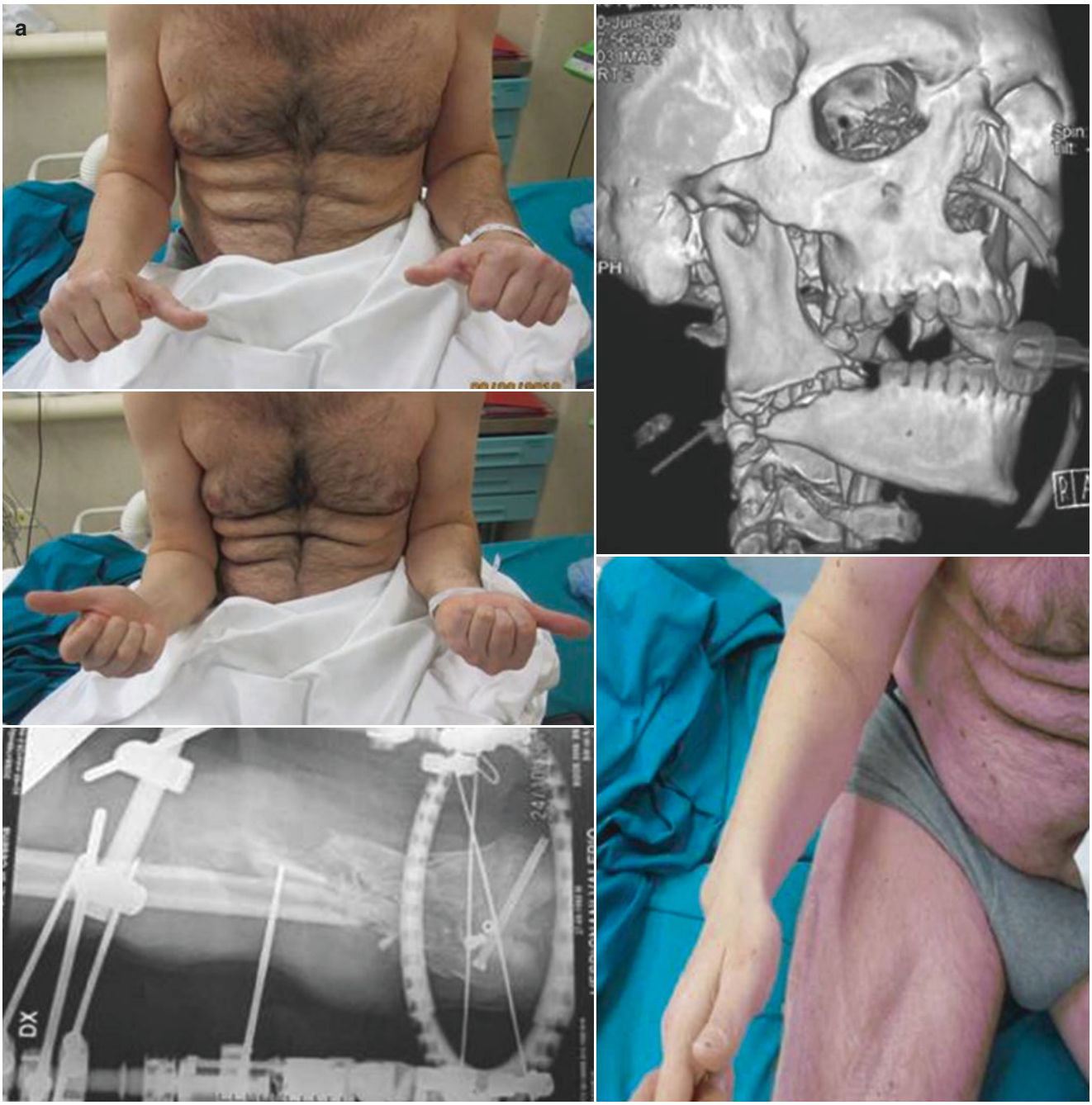


Fig. 22.11 (**a**–**g**) Chronic Essex-Lopresti lesion in V.V., a 43-year-old male; a sales agent who was right-handed. Four years previously he had been involved in a car accident and had sustained multiple traumatic injuries (maxillo-facial, bilateral open femurs, right upper limb), treated at another hospital. He presented with a weak right forearm with dorsal wrist deformity, pain on supination, and poor grip strength; range of motion was good. X-ray and magnetic resonance imaging (MRI) showed a previous ulnar synthesis, RH resection, and 2.5-mm proximal radial translation; the IOM and triangular cartilage were disrupted (**a**). Preoperative imaging in this patient (**b**). Preoperative assessment under narcosis; axial stress test showed bone realignment but proximal transverse instability (**c**). Long lateral-ulnar approach: trial of an RH prostheses showed it was really unstable, and we had to remove it. The lateral collateral ligament was reconstructed. After the first plate removal a distal shortening (1 cm) osteotomy showed good DRUJ alignment (**d**). A posterior tibialis graft was passed through a 2.5-mm radial tunnel. The neoligament was fixed to the bones with a transosseous tie. Note the proximal distance between the two bones, which determined the irreducibility of the prosthesis; IOM plasty did not stabilize the transverse instability. In these complex cases it may be necessary to consider a PRUJ plasty as well. The DRUJ was judged to be stable. In this patient we immobilized the forearm for 3 weeks (**e**). Follow-up at 55 months: there was good elbow stability, bone realignment, and grip strength (**f**). The osteotomy had healed, and the ligament well recognized on MRI. The patient mentioned that noise occurred on pronosupination. The MEPI was 85/100 (**g**)

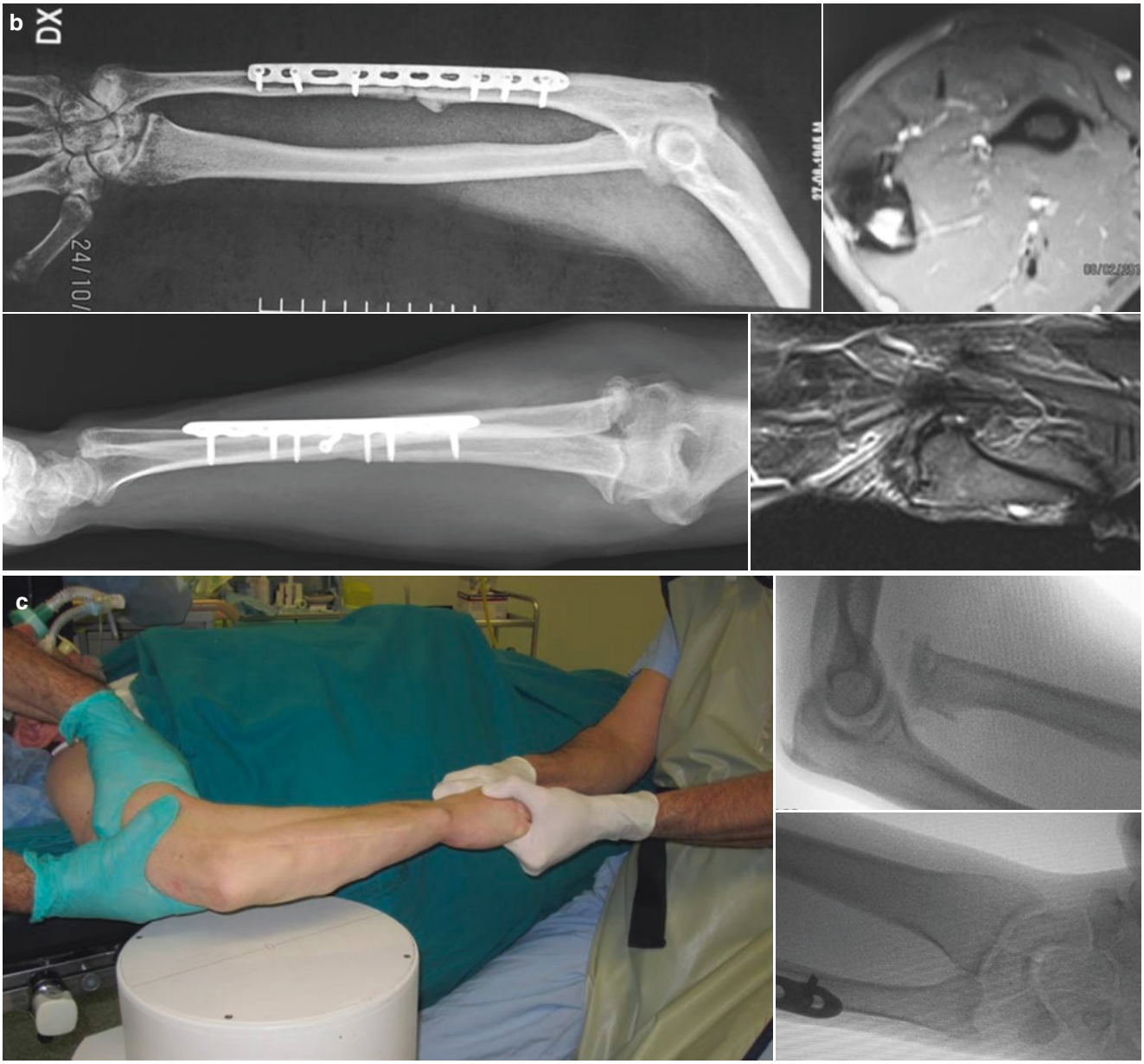


Fig. 22.11 (continued)

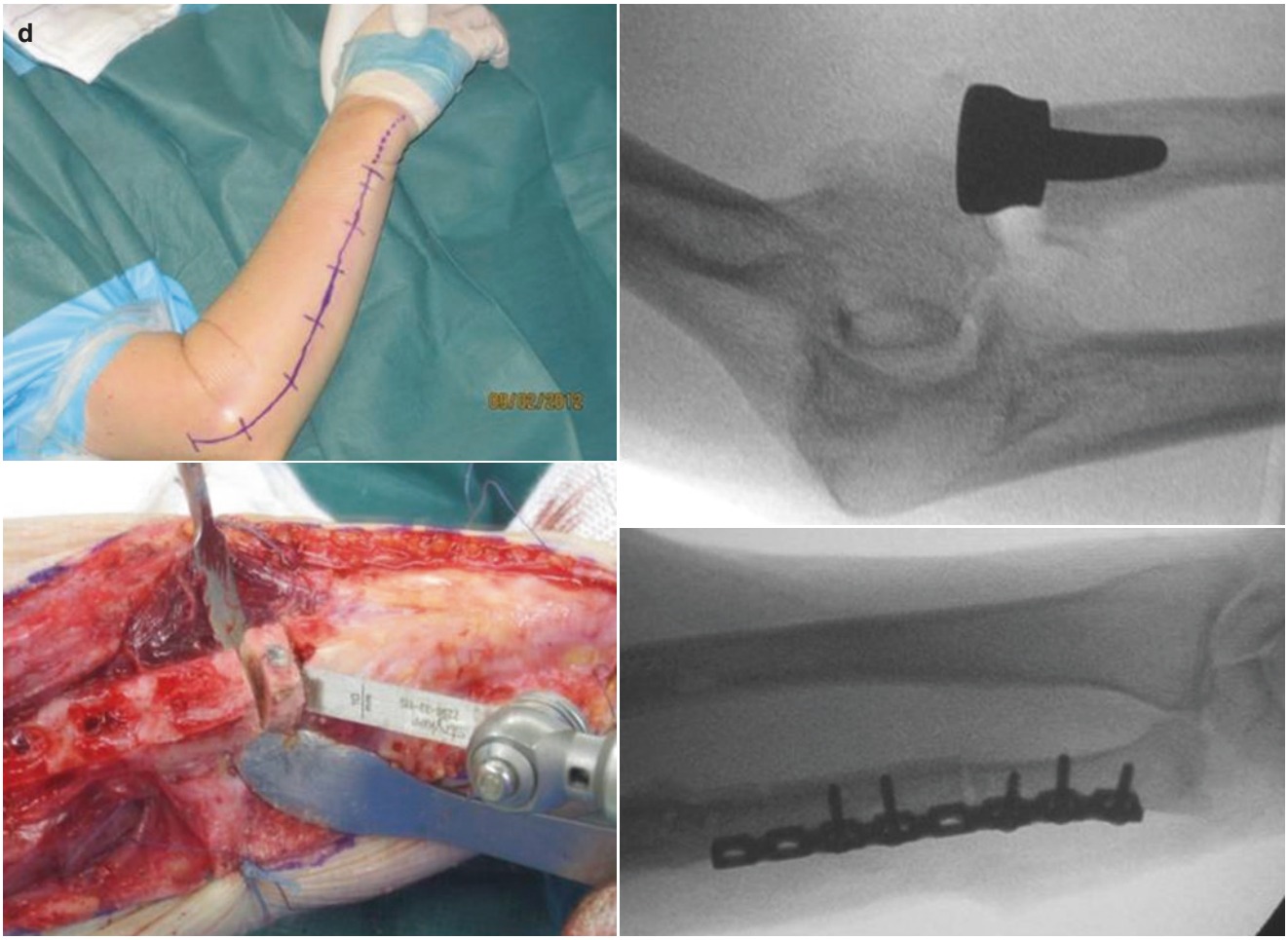


Fig. 22.11 (continued)



Fig. 22.11 (continued)



Fig. 22.11 (continued)

22.5 Results

There have been few reports of long-term follow-up of ligamentoplasties. Marcotte and Ostermann (2007) reported their results for 16 patients, all affected by chronic Essex-Lopresti lesions, at 78 months of follow-up; no patients needed secondary surgery and grip strength had improved from 59 to 86% of that in the unaffected limb. No patient was worse, in terms of pain or function, than before the surgery, while in 15 of the 16 patients wrist pain had lessened. In our small short-term experience (six patients, all male, two with acute and four with chronic Essex-Lopresti lesions), at 18 months we reported a median Mayo Elbow Performance Index of 89/100, this being a result of approximately 10° less supination (imperfect ligament isometry, absent DRUJ plasty). There was no referred pain; and three patients showed rapid radial neck reabsorption.

Conclusions

Fractures-dislocations of the forearm must be classified as unstable fractures of the forearm, because they damage the functional unit of the forearm, which is stabilized by three constraints. Monteggia, Galeazzi, and criss-cross injuries, as well as Essex-Lopresti lesions, must be included in this category because the fracture of one or both intra-extraarticular bones is associated with instability of at least two of the three forearm constraints. Correct clinical evaluation and early treatment are critical for the successful treatment of these lesions; late treatment is often related with poor outcomes.

Essex-Lopresti lesions represent disruption of the three constraints of the forearm and treatment of these lesions is very challenging. RH reconstruction or substitution and DRUJ stabilization are well-known treatment procedures. IOM reconstruction plasty is a well-planned technique and many authors agree on its necessity in both acute and chronic lesions, but results are still few and not homogeneous. Furthermore, the progression of partial IOM tears is still not clear, and forearm microinstability, which creates chondral erosion against capitellar prostheses and causes pain-free rapid stem loosening, needs to be elucidated.

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Traumatic Lesions of Peripheral Nerves at the Elbow

23

Claudio Rovesta, Maria C. Marongiu, Luigi Tarallo, and Fabio Catani

23.1 Introduction

The main nerves to the forearm and the hand (ulnar, median, radial, medial, or lateral cutaneous) pass from the elbow and not rarely a direct or indirect elbow trauma with fracture or dislocation, knife wound, and severe bruise can achieve a lesion. This lesion of peripheral nerve can be made for a mechanism of stretching (or elongation) because the nerve in its course presents points of fixity that anchor it to nearby structures and restrict its sliding by making it more vulnerable to traction (under arcade of Osborne for the ulnar nerve, under pronator teres muscle and flexor jaw for the median nerve, and under arcade of the supinator muscle for posterior interosseous nerve).

Other methods of lesion are direct compression or shear due to injury by glass or by blade or by cutting fracture stumps (radial nerve in distal humeral diaphysis).

We have to discriminate nerve injuries between *acute or immediate* occurring during trauma or during maneuvers of reduction or traction or also performing surgical osteosynthesis or prosthesis and *chronic or delayed* due to physiotherapic maneuvers or compression by an exuberant fracture callus or stretching by nonunion or poor consolidation (e.g., supracondylar malunion or pseudarthrosis with cubitus valgus and consequent ulnar nerve progressive stretching).

We also need to differentiate peripheral nerve lesions occurring in trauma of *children* and of *adult patients* because they have different evolution and treatment even if they have some common characteristics are to be found in certain fractures which we know to have more opportunity to give a nerve lesion and we need to do a diagnosis only by clinical evaluation in urgency (this is especially difficult in children).

In fact the instrumental evaluation do not help us a lot in establishing the diagnosis in acute cases (Matev 1976; Padua et al. 2013) (in limited number of cases the ultrasound can document the continuity or discontinuity of the nerve and only after 1 month from the lesion is valid the use of EMG).

In urgency surgical treatment is indicated when the nerve damage is associated with vascular deficit and when the nervous deficit is associated with displaced fractures hardly reducible in an unbloody manner (with the risk of a further damaging of the nerve during maneuvers for reduction).

We distinguish late lesions of adults and children between acute injuries that did not recover spontaneously after 4–6 months despite proper physiotherapy treatment and lesions that take place later as outcomes or complications of fracture or its treatment.

In all these lesions, revision surgery and type of reconstruction should be planned according to the clinical, instrumental (EMG), and functional deficit. External only or internal and external neurolysis are performed on nerves with partial lesion or compression lesions. In total lesions without recovery, we do nerve grafts using sural nerve. When it is not possible to reconstruct the nerve for recovering a muscular function, we have to do muscle and tendon transposition.

The physiotherapic treatment is especially important for maintaining good joint movement and for improving muscle and sensory recovery and for encouraging mechanisms of compensation which make up for a partial recovery of the lesion.

23.2 Surgical Technique and Rehabilitative Treatment in Acute Injuries: In Children

Peripheral nerve lesions have a frequency of 10–15 percent in supracondylar fractures (Gartland 3–4 type) in children under 14 years and mainly concern deficit of median nerve (or anterior interosseous nerve) or radial nerve. It is important to do clinical diagnosis despite the poor cooperation of the young patient (Lipscomb and Burleson 1955). Hard to assess the deficit of NIA which shows an apparent normal

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flexion and extension of wrist and fingers, we have to show specific deficit of flexion of distal phalanx of thumb and 2° finger (Spinner and Schreiber 1969).

The indication for an open treatment to revise the nerve is absolute and urgent if there is also a vascular deficit (Wilmshurst et al. 1989), or if the nervous deficit is associated with important breakdown of fracture (Gartland 3–4) and when nervous symptoms appeared or worsened immediately after admission (mobilization of the stumps with possible nerve damage or incarceration).

Impaired vascular lesions suggest to have a vascular surgeon in team with the young patient supine under general anesthesia without tourniquet and preparing to use intraoperative fluoroscope that can be moved easily into and out of the operative field to assist with pinning of the fracture.

The surgical incision goes from medial bicipital-tricipital sulcus to the anterior antecubital fossa of elbow. This allows us to isolate the brachial artery before the bifurcation and the median nerve above the medial intramuscular septum and follow them distally by cutting the lacertus fibrosus. Dissection proceeds until the metaphyseal spike is encountered: it is covered by a small amount of tissue and parts of the brachialis muscle that may be torn. At this point, the neurovascular bundle should be located and evaluated reducing the compression by the proximal fracture stump. Often after this maneuver, we have a reappearance of the radial pulse. (Rarely, it is necessary an arteriolysis or deobstrution or arteriorrhaphy or graft by the vascular surgeon.) Fracture reduction is difficult because the distal fragment is posterior and lateral and the periosteum is folded over its surface. Reduction is obtained extending the cut edge of the periosteum then a periosteal elevator can be used as a lever to bring anteriorly the distal fragment and reduce it to the shaft stump. Once a reduction has been obtained, the fracture is fixed with smooth Kirschner wires (two lateral and one medial divergent and engaging the medial and lateral column of the distal fragment) using fluoroscopy. Then we can see the continuity of the median nerve until anterior interosseous nerve origin. The ulnar nerve, if interested by a lesion, must be insulated sectioning Osborne's epitroclea ligament and proximal arch of flexor ulnaris carpal muscle (F.U.C.). Lateral and anterior approach is useful when we have a deficit of radial nerve without vascular deficit. Often it is stretched by the proximal fragment, and we have to release it until the supinator arcade.

Neurolysis of the nerve and its position not in direct contact with the fracture is sufficient for an excellent recovery in the months ahead.

Very rare is a complete nerve injury and hence the need for a termino-terminal neurorrhaphy to be performed with the use of optical means (microscope or loops) 8/0 suture and triangular needle.

In our experience at the Orthopedic Clinic of the University of Modena and Reggio and from January 2006 to June 2011, we admitted 92 children from 1 to 14 years with supracondylar fractures of the humerus. Among these, 68 % are type 3–4 of Garland and 26 % are type 2 of Garland and 6 % type1.

Among13 cases(14, 5 %) with acute peripheral nervous lesions, in 3 cases a vascular deficit (no radial pulse) was associated. The deficit of nerve was in four cases for the median nerve, in four cases for the NIA, in three cases for radial nerve, and in two cases for ulnar nerve. We treated with open reduction technique 12 cases. In one case after intraoperative arteriography, an unblocking was performed, and in two cases, we obtain resumption of peripheral circulation with simple avventiziectomy.

Only in one case we performed direct neurorrhaphy of median nerve for subtotal break by the proximal fracture stump. In other cases, an external neurolysis was performed. After removal of cast and K wire, nine patients had a physiotherapic treatment aimed at progressive recovery of articular movement and muscular and sensitive deficit. In those young patients, we had an excellent recovery in 11 cases, good in 2 (residual deficit in M3–4 in distal ulnar muscles and in a NIA lesion a recovery in M3–4 of FLP e Fl. Pr. 2°) in a period from 4 to 14 months (Fig. 23.1).

Other causes of nerve damage may occur in the dislocations of the elbow (median nerve) in Monteggia fracture (Stein et al. 1971; Watson and Singer 1994) or displaced radial head fracture (posterior interosseous nerve) or in fractures of the epitroclea treated surgically (ulnar nerve) during maneuvers of reduction and osteosynthesis without isolating ulnar nerve (Spinner et al. 1968).

Iatrogenic lesion of the ulnar nerve could happen in the application of the olecranon traction wire or in closed supracondylar fracture when medial – entry pins are placed with the elbow in 90 degrees or more of flexion from epitroclea to get greater stability of synthesis. In these cases, you should make a small incision of 1 cm on the epitroclea; blunt dissection is performed down to the level of the bone of medial epicondyle assessing starting position and trajectory under fluoroscopy guidance.

We think that rehabilitative treatment in those little patients is useful in preventing articular stiffness by splints during rest and exercises of mobilization and grasp performed also by parents trained by physiotherapist. During reinnervation, it is important to strengthen muscles and facilitate manual activity and sensitive recovery using games and playing activities.

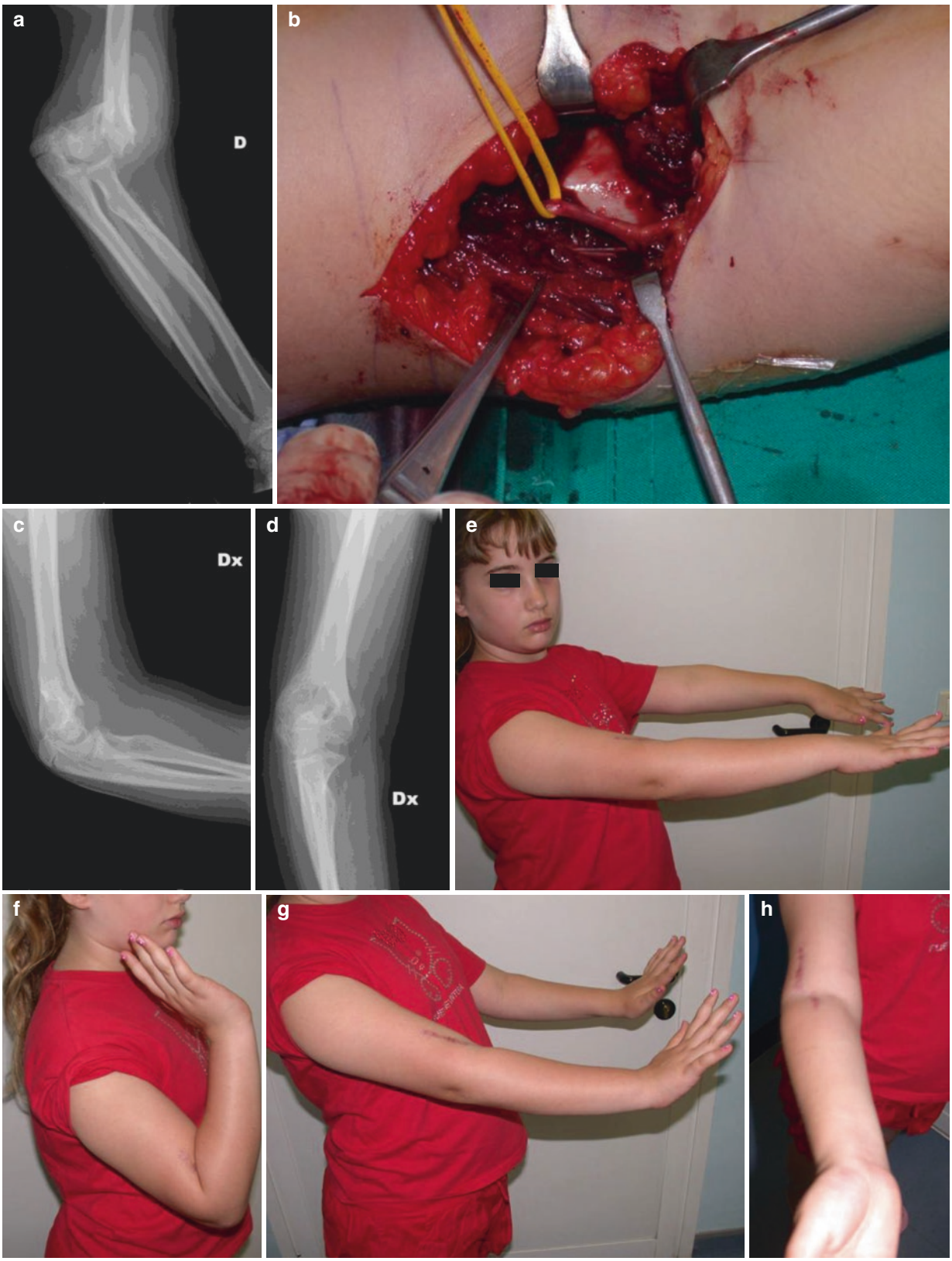


Fig. 23.1 (**a**) P.C., girl 10 years old with a Gartland 3 supracondylar fracture with deficit of radial nerve. (**b**) Intraoperatory picture of the radial nerve stretched on the proximal stump of the fracture. (**c**, **d**) good consolidation of fracture after 4 months. (**e**, **f**) good extension and flexion of the elbow. (**g**, **h**) complete recovery of radial nerve and good scar after 6 months

23.3 Surgical Technique and Rehabilitative Treatment in Acute Injuries: In Adults

In adult patients, the lesions of peripheral nerves at the elbow are observed mostly in spiroid fractures of the distal humerus (fracture of Holstein with radial nerve injury) (Fig. 23.2), in olecranon- and epitroclea-displaced fractures (ulnar nerve) in supraintercondylar humeral fractures of median and ulnar nerves (Cotton 1929; Galbraith and McCullough 1979) and also in dislocation and fracture-dislocation (Hallett 1981; Mannerfelt 1969; Rana et al. 1974).

In our Orthopedic Clinic from 2008 to 2013 in a series of 64 patients with over-intercondylar, trochlear, medial, and lateral condylar fractures, we had three nerve damage (two of the ulnar nerve and one of the radial nerve) in continuity.

Very abundant literature on radial nerve injuries shows that 80 % percentage around these injuries recover spontaneously without need to be isolated and treated surgically. In 20 % of patients whose will not have a spontaneous recovery, when it is indicated an early surgical revision ?

In our experience in fractures of Holstein, in displaced articular fractures of the distal humeral epiphysis (C2–C3 of A.O classification), and in nerve lesion occurring after reductive maneuvers or nervous deficit worsening with time, it is indicated to have an early surgical revision of nerve and an open osteosynthesis.

The most widely used surgical access for fractures of distal humeral epiphysis is back with the mobilization of triceps or by a transolecranic osteotomy (in Chevron).

This allows an ulnar nerve insulation that must always be performed in these operations with an eventual anteposition to the end of the surgical procedure. The radial nerve can be isolated in biceps-tricipital space -12 cm proximally from the lateral epicondyle, or distally in the space between brachioradialis muscle and anterior brachialis muscle and then followed proximally.

In isolating the nerves, except that they are not incarcerated in the fracture site, we will proceed to a stable osteosynthesis of the fracture (plate and screws, external fixator, etc.), and then we proceed to the treatment of nerve damage.

Frequently, if nerve injury is in continuity and an external neurolysis is sufficient, then we have to place the nerve not close to the fracture site and not adhering to the osteosynthesis device to avoid secondary compression by fracture callus or a difficult operation for removal of metallic device with iatrogenic risks of nerve lesion.

In case of a complete interruption of the nerve, when the gap is less than 1 cm (i.e., cutting injury), we proceed to a termino-terminal neurorrhaphy, by 7/0 or 8/0 nylon, with a triangle needle and optical means (loops or microscope). Use of fibrin glue is useful to reinforce the sutures.

When the gap is greater than 2 cm and the stumps are very damaged (drawing injury or entrapment), we should align with the 2/0 or 3/0 suture that connect them away from site of fracture placing a strip of muscle or subcutaneous tissue. After consolidation of the fracture, it will be easy to find nervous stump, resect it to find good nervous tissue, and connect it by sural autologous grafts.

In elderly patients with a complete nerve lesion, it may be useful to program immediately a palliative (i.e., in radial deficit FUC transplant pro ECD).

In the treatment of trauma (fractures and dislocations), we can have iatrogenic injury in adults as radial nerve injury by distal fiches of external fixator of the ulnar nerve during osteosynthesis of humeral epiphysis or olecranon with plates, NIP in osteosynthesis of the radial head, and the radial diaphysis. In a recent publication which collected nine record of cases with 226 interventions of internal fixation of distal humerus, fractures are reported as complication 24 nervous lesions (19 ulnar, three radial, two median) and five of these cases have required secondary nerve revision surgery.

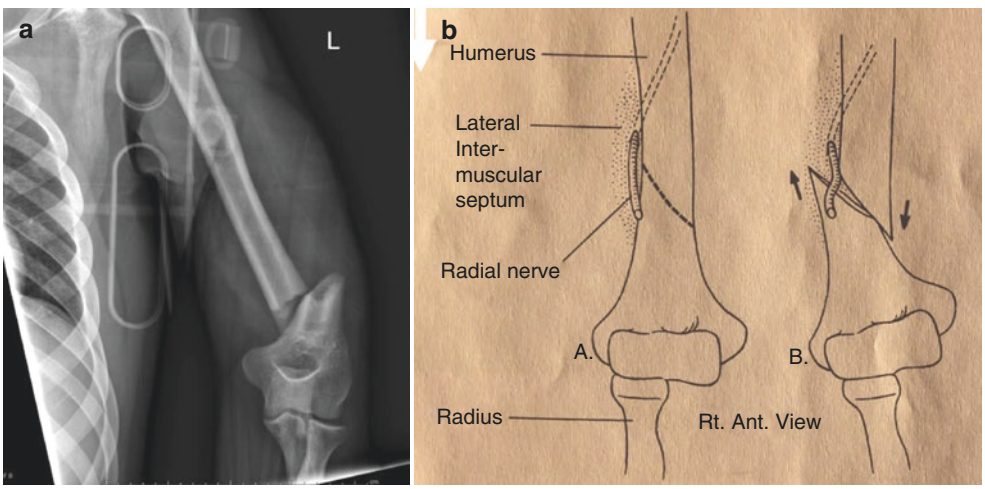


Fig. 23.2 (**a**) Classic Holstein fracture at distal humerus. (**b**) Schema of stretched or compressed radial nerve in these fractures

Sometimes it is possible to have iatrogenic lesion of peripheral nerve at elbow using external fixator or in arthroscopic procedures (Birch et al. 1991; Hahn and Grossman 1998).

When we decide not to go to isolate nerve lesion because we think it is an injury consistent with a good chance of spontaneous recovery, in addition to the treatment of the fracture, we must program the clinical and instrumental evaluation and the physiotherapy treatment of nerve damage.

First we must inform the patient about the time of recovery, no immediate, which depend on the distance between the injury site and denervated muscles and anesthetic skin areas (considering a nerve regrowth of a 1 mm. per day) and on the possibility of a partial recovery.

Physiotherapeutic advice will be useful for planning the treatment of peripheral nerve deficit compatibly with healing of bone and with tendon- and muscle-associated injuries.

From day one, however, we recommend passive mobilization of distal joints trying to do active mobilization.

Splints of thermoplastic packaging are useful to maintain proper posture at rest preventing the establishment of joint stiffness (e.g., wrist extension and MF extension in radial nerve paralysis).

Clinical monitoring to verify the progressive recovery of peripheral nerve lesion should be done every month, recording data that allow us to evaluate an eventual recovery in time.

For this with an initial complete paralysis (M0) and sensory deficit (S0), we will assess an initial motor recovery in most proximal muscles (graduated from M1–M5) and more proximal cutaneous territories (S1–S4). In the absence of a clinically detectable, subjectively reported recovery, it is good to sign Tinel level involving percutaneous percussion with your index finger on the nerve from distal to proximal direction: a feeling of pain or tingling in the site of percussion highlight to us the face of regeneration of axons along the nerve.

The measurement with anatomical landmarks like the radial styloid or anterior transverse plica of elbow allows us to have a real idea about reinnervation over the time.

As for the EMG, it makes no sense to run it before at least 1 month from the lesion because this is the minimum time in which are established electromyographic signs of axonal injury in muscles (fibrillation potentials and PSW aside) besides the absence of voluntary activity and absence of wave M in muscle after nerve stimulation.

Initially electromyographic evaluation is important to determine whether nerve injury is total or partial (denervation at rest but with a limited voluntary activity, wave M with reduced amplitude).

It is advisable to repeat the EMG after 2 months because in the absence of visible clinical recovery, more proximal muscles may show some potential of low-amplitude, polyphasic (rising potential) testifying the initial reinnervation of some muscle fibers.

This initial rehabilitative treatment to promote reinnervation must guide muscle recovery with physical therapy with muscle stimulation movements that activate the muscles in shooting. In these phases, the reinnervation can be accompanied by painful sensations, abnormal sensations even at rest so they can serve physical therapy with analgesic effect as TENS in addition to neurotrophic drugs for control of neurogenic pain. An additional check after 2 months can show progression of activities in the proximal muscles and initial activity in the distal musculature.

Reached a good clinical recovery, EMG evaluation only makes sense to evaluate particular problems such as no selective recovery in certain muscles, evaluation of conduction velocity in sites where compression is suspected. When after 4–6 months in the distal but also in proximal lesions we have no clinical and electromyographic signs of recovery, we must consider the possibility of a surgical revision.

In recent years, we are using the ultrasound or MRI to evaluate the continuity of peripheral nerves (Ng et al. 2011) at the elbow, but this technique requires experienced operator and an anatomic continuity not ever correspond to a functional activity. In fact, when you highlight a continuous nerve, lesion cannot know if this is just scar tissue or represents a true continuity not only anatomical but also functional with a good chance of recovery.

These methods may be useful in diagnosing a complete rupture with nerve gap necessitating revision surgery and early reconstruction without waiting for an impossible spontaneous recovery (Fig. 23.3).

23.4 Surgical Technique and Rehabilitative Treatment in Late Posttraumatic Peripheral Nerve Lesions

In some cases we may have the appearance of a late posttraumatic peripheral neuropathy such as in the outcomes of fractures and dislocations for exuberant callus or scar adhesions with compression or progressive stretching of ulnar nerve as in cubitus valgus from chronic instability of the elbow (Rovesta et al. 2015). Pseudarthrosis of supracondylar fractures or unrecognized Monteggia can stretch radial nerve or posterior interosseous nerve. It is not uncommon to have an iatrogenic ulnar nerve injury during rehabilitation treatment in the forced mobilization of the elbow in flexion. In fact, if the nerve was not put in anterior position before it can be coated without scrolling in the cubital canal and in case of forced flexion, it can be stretched and damaged (Fig. 23.4).

Late surgical revision of lesions of peripheral nerves is to be carried out after 4–8 months from trauma (no more than 12–14 months) when we had an absent recovery or minimal recovery but clinically and electromyographically stabilized from 3–4 months. Before the surgical procedure, we need to

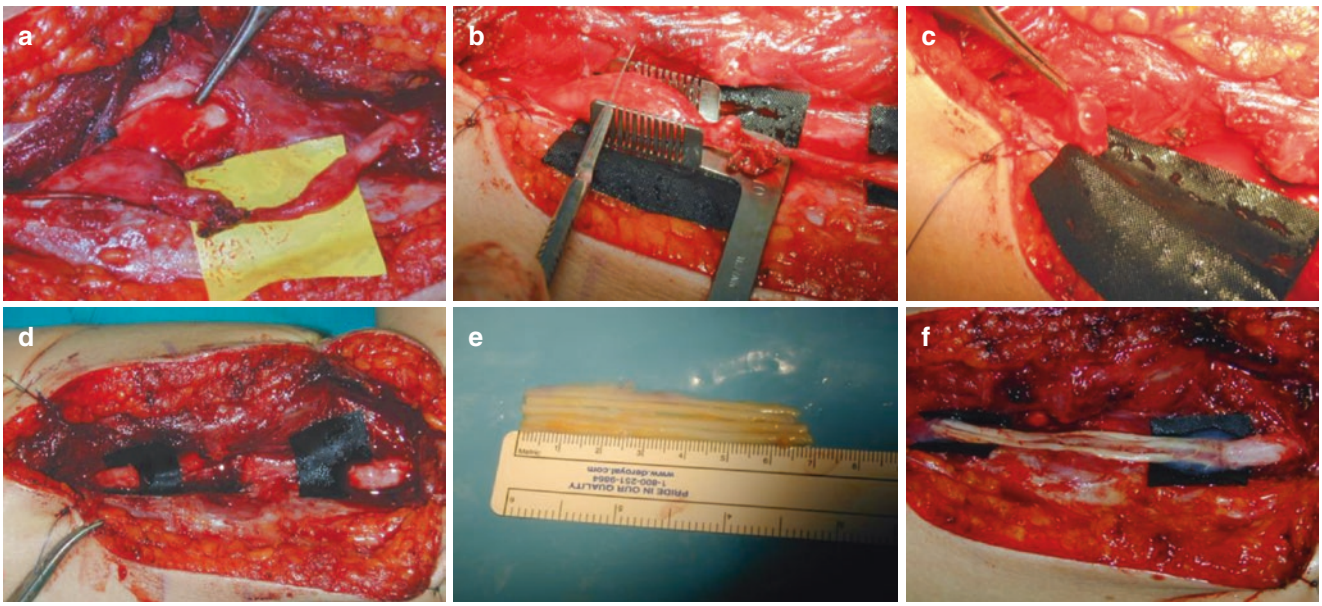


Fig. 23.3 Late revision of radial nerve lesion after 8 months from trauma without any recovery. (**a**) Discontinuity of the nerve. (**b**, **c**) Resection of nerve stumps and evidence of fascicular structure. (**d**) Evidence of final gap. (**e**, **f**) Preparation of nerve grafts of autologous sural nerve and final suture of grafts

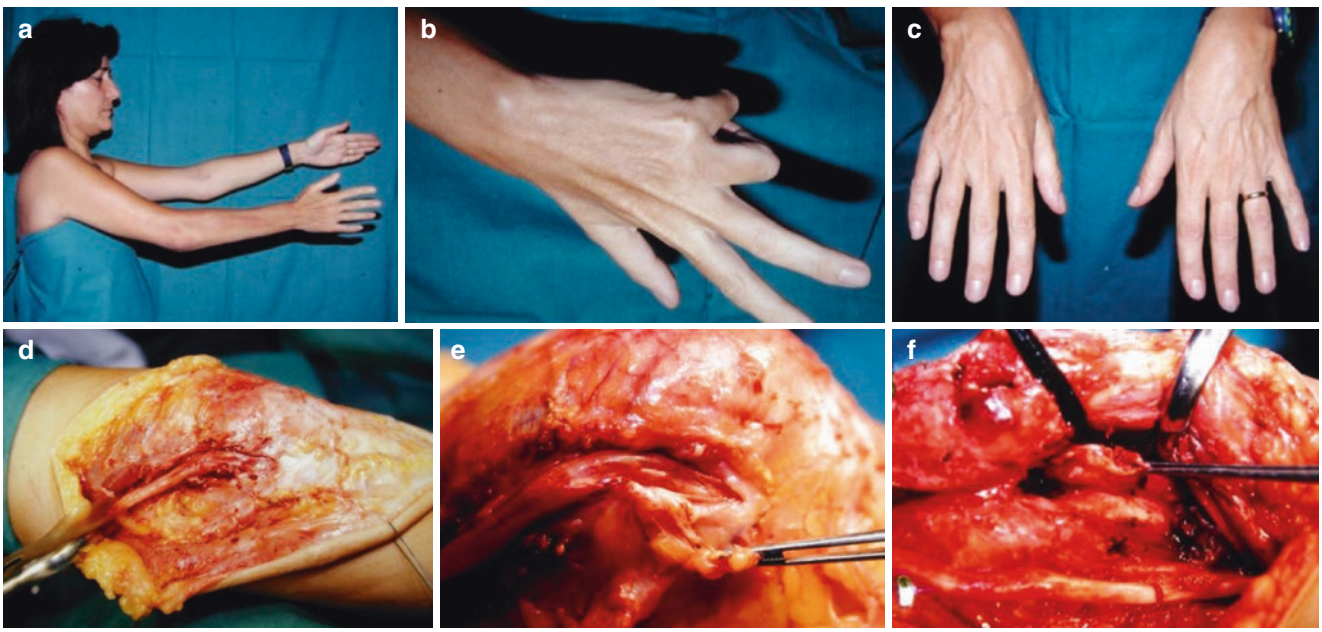


Fig. 23.4 A.D., woman 48 years old. Stiffness of the elbow after olecranon fracture with ulnar palsy after a mobilization in flexion. (**a**–**c**) Stiff right elbow with muscular atrophy by ulnar palsy. (**d**, **e**) Surgical revision in lateral decubitus of ulnar nerve fixed by abundant scar it in the cubital tunnel. (**f**) After external and internal neurolysis posterior capsuloplasty of elbow

identify exactly the level of injury ruling out that sometimes there's a multilevel lesion (e.g., elbow and the brachial plexus, elbow, and wrist) (Ng et al. 2011). Depending on the affected nerve and on the type of injury, we program the surgical incision in order to isolate the nerve proximally where we have healthy tissue (e.g., medial bicipital-tricipital groove for median and ulnar nerves) or distally for radial nerve (between brachialis anterior and brachioradialis muscle) to be able to follow and isolate the abundant scar tissue that surrounds it.

Frequently, we have a nerve in continuity with significant macroscopic distortion.

Useful in such cases intraoperative electrophysiological instrumental evaluation with simple proximal and distal

nerve stimulation with recording directly on the nerve of the nerve action potential (NAP) through the lesion. The absence of functional continuity leads to resect a tract of injured nerve until evidence of healthy tissue (well-defined fascicular structure) on the proximal and distal stump. In other cases, it may have a nerve break or even a stump incorporated in the fracture callus. Even in these cases, after resection of the stumps will restore the continuity of the nerve by autoplastic nerve grafts.

Frequently, we use contralateral sural nerve and being the caliber of sural nerve smaller than the nerve to reconstruct we can do 2 or 3 or more parallel implants from 3 to 10 cm (depending on the gap) covering surface of the stumps. The graft length must be such that it does not power up sutures even in maximum flexion-extension or prono-supination of the elbow. The epi-perineural suture between the stump and sural grafts typically are performed with 7/0 or 8/0 nylon with optical means (microscope or loops). We try to recreate the continuity of the nerve and its correct rotation with "vasa nervorum" and the morphology of the fascicules. To give more resistance to suture, twitchy with points is completed with fibrin glove which creates a sleeve on the two proximal and distal sutures (Fig. 23.3).

Typically after this surgery it needs an immobilization of elbow for about 3 weeks by cast or valve allowing the suture a wound healing without any initial tensions.

In this case from the proximal stump axons regrow distally with an approximate speed of 1 mm per day first surpassing the proximal suture, crossing the grafts then passing the distal suture and take the distal part of the nerve for innervation of distal muscles and specific cutaneous zone. The same considerations made for acute injuries about clinical and instrumental evaluation are available waiting muscular and cutaneous recovery. Rehabilitation is always of great importance in keeping the elbows but especially wrist and hand mobilization and a good trophism in areas innervated despite the deficit.

The establishment of an adaptation of the muscular function is natural but should be favored when the lesion is established and there are no more recovery prospects.

In the initial phase of recovery highlighted with the EMG and with minimum activity (M1–M2), more proximal muscles is important to foster and strengthen this activity with exercises that involve individual movements and then more complex functions of the wrist and hand as power and precision grasp. Also useful tactile protective sensory reeducation and then discriminatory. After reconstruction by grafts of a peripheral nerve at the elbow or 3° lower arm (radial or ulnar or median nerves) at a distance of 12–18 months, we can consider stabilized recovery even if in certain cases we observed for further 1–2 years till minimal reinnervation.

The stability of the clinical picture and sensory and motor instrumental evaluation allows us to judge the recovery obtained as absent, poor, quite good, good, or excellent and how this fits into the functionality of the limb subjectively and objectively with assessment protocols such as the SF36 et al. In case of unsatisfactory recovery despite a correct rehabilitation, who seeks to take advantage of synergistic muscles, strengthening compensation movements, we must consider according to the deficit if there is a chance improve function. Palliative surgery with musculotendinous transfer can be a solution: for example, persistence deficit in territory of the radial nerve when the territory of median and ulnar are intact and there are no particular tendon injuries, we can use the FUC pro ECD and FS4 pro ELP.

In this case and in all palliative surgery, it is important the designation of tendon to transpose, using synergistic muscles with tendons with sufficient sliding and strength (at least M4) ensuring a valid suture of tendon made in proper tension tendon transfer can be completed by surgery on the capsule (capsular slack), or tenodesis, or correcting osteotomy or arthrodesis.

After an immobilization of approximately 1 month in correct position to encourage proper healing of sutures performed, you can start a gradual mobilization passive before and then active. Compliance of patients and the role of rehabilitation is fundamental for a good result biofeedback techniques are useful in these patients to recovery muscular function.

Conclusions

Peripheral nerve lesions in acute trauma of the elbow are not particularly frequent but are to be found especially in fractures more at risk where the fractured bone is close to the nerve, in fracture-dislocations where trauma created an important joint and bony stumps diastasis. Also in deep wounds, trauma from pulling the elbow with tendon and muscle injuries is possible a lesion of peripheral nerves. The diagnosis of peripheral nerve lesion in urgency is clinical because instrumental tests (EMG, MRI) are of little use in urgency.

Early surgical revision of nerve with clinical deficit in acute trauma should be made in displaced fractures and when you suspect a chance of further injury with reductive maneuvers. Usually, we see an anatomical continuity of the nerve and just an external neurolysis positioning it away or separated from the fracture site is sufficient. In the case of partial or total lesion from clean cut you run a termino-terminal neurorrhaphy with optical means. In total nerve lesions from stretching or squishing with fraying of the stumps, they are combined with a locator string, moved from the fracture site. After fracture consolidation, we find again nerve stumps, aided by locator string, we resect scar tissue, and we perform autologous grafts by sural nerve.

When we haven't done surgical evaluation of the nerve in urgency and this nerve does not present clinical and instrumental signs of recovery after 4–6 months, late review must be carried out and any secondary reconstruction with grafts. The palliatives can also be used at an early stage in elderly patients with nerve damage which would have little chance of recovery or belatedly after 12–18 months in the absence of muscle recovery or to complete a partial recovery.

Physiotherapy and rehabilitative treatment are of considerable importance at different stages of treatment: maintenance of a satisfactory joint mobility and keeping the limb during total deficit, stimulate progressive muscle reinnervation and consequent functional recovery then complete and refine motor and sensory recovery, and promote muscle synergy and quality of sensitivity and functional recovery at the end of reinnervation. Other function of physiotherapy is in control of neurogenic pain from injury (neuroma, crush) then from hyperesthesia and dysesthesia during reinnervation. Addition to medications are useful methods of physical therapy for pain management esp. TENS.

In the postoperative treatment of muscular transfers, biofeedback techniques and exercises are important for muscle contraction moved to create a new action. Relationship between the patient, the physiotherapist, and the orthopedist is fundamental to follow the various stages of nerve damage, its recovery, or the need and timing of additional surgeries to reach the best functional outcome possible.

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Vascular Lesions at the Elbow and Compartmental Syndrome

24

Roberto Adani, Raffaele Mugnai, and Luigi Tarallo

24.1 Introduction

Direct elbow trauma may significantly affect vascular and nervous structures, with severe immediate and long-term lesions.

24.2 Vascular Lesions

Vascular injuries occur in 5–13% of elbow dislocations (Endean et al. 1992; Sparks et al. 2000) that represent the third most frequent orthopaedic injury after glenohumeral and patellar-femoral dislocations. Closed dislocations are rarely associated with arterial injury (Grimer and Brooks 1985); Marcheix et al. (2005) reported three cases of rupture of the brachial artery after closed posterior dislocation. Arterial damage is generally associated with open anterior or posterior dislocations (Fig. 24.1) and other associated upper extremity compound injuries (Endean et al. 1992; Marcheix et al. 2005; Squires and Tomaino 2003). In displaced supracondylar fractures of the humerus in children, the incidence of an absent radial pulse with a possible brachial artery injury ranges from 2.6 to 20% (Shaw et al. 1990; Griffin et al. 2008; Blakey et al. 2009). The posterolaterally displaced Gartland type III injury (Rasool and Naidoo 1999) has the highest incidence rate of supracondylar fracture due to the absence of continuity between the fracture fragments. The brachialis muscle protects the anterior neurovascular structures from damage, but in case of severe displacement, either medial or lateral, the spike can penetrate the brachialis muscle increasing the risk of neurovascular complications. With posterolateral displacement of the distal fragment, the spike penetrates medially and the median nerve and the brachial artery may be entrapped (Lyons et al. 2000) (Fig. 24.2).

Loss of pulse does not preclude an attempt to close reduction. The initial treatment for a patient with a displaced supracondylar fracture with a pulseless but well-perfused hand is closed reduction under general anaesthesia and percutaneous K-wire fixation (Choi et al. 2010). The reduction manoeuvre should be carefully performed, first with an axial traction to restore the extremity length and then applying flexion to the elbow, thus reducing the risk of entrapping neurovascular structures within the fracture fragments. If the reduction cannot re-establish the arterial flow (absence of the wrist pulse and a poorly perfused hand), the patient should be considered for surgical exploration. Controversy remains regarding the management of an absent radial pulse in an otherwise perfused hand (Shaw et al. 1990; Griffin et al. 2008; Choi et al. 2010; Mehlman et al. 2001; Schoenecker et al. 1996; White et al. 1996). Some authors (Griffin et al. 2008; Choi et al. 2010) consider that reduction of the fracture is sufficient and the absence of the pulse alone is not an indication for immediate vascular exploration if there are no other signs of ischaemia. For others (Mehlman et al. 2001; White et al. 1996) the absence of the pulse indicates arterial injury even when the hand appears pink and warm, implying that this occurrence does not guarantee adequate circulation to the forearm muscles and the hand.

An effective evaluation of the vascular damage should include both clinical and instrumental parameters. The role of angiography in the treatment of these patients is not clear. The use of arteriography is deemed unnecessary, as it might cause delayed treatment with prolongation of ischaemic time between fracture and reduction and possible arterial damage at the site of catheter insertion (Shaw et al. 1990; White et al. 1996). Few authors still (Sabharwal et al. 1997) suggest arteriography to better define location and extent of the vascular injury as well as the presence of a collateral circulation. The assessment of brachial artery patency by non-invasive imaging is now possible with the use of MR

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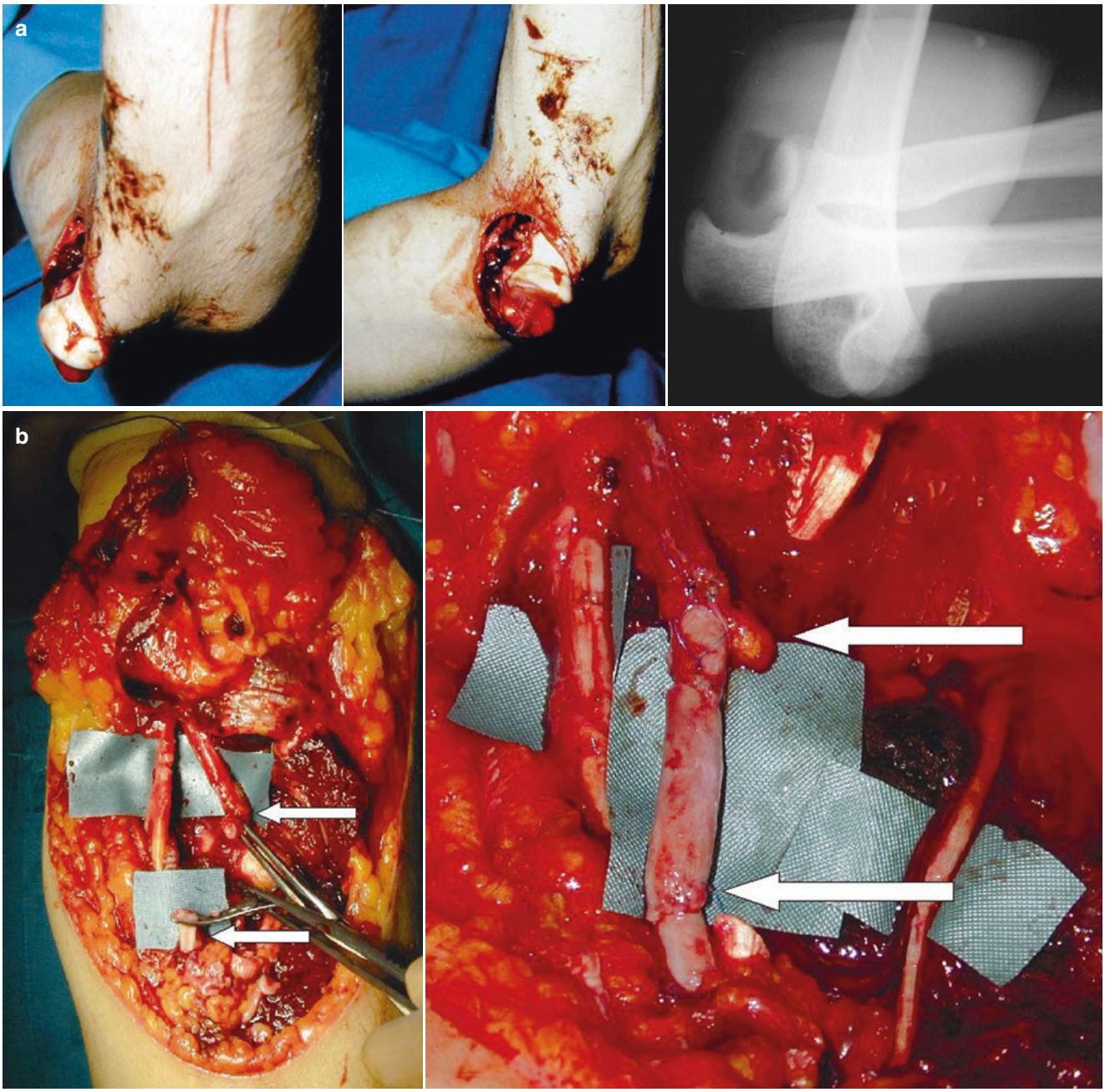


Fig. 24.1 A 37-year-old man sustained an open posterior-lateral elbow dislocation (**a**). His hand was cold and ischaemic, and radial and ulnar pulses remained absent after reduction. Surgical exploration revealed complete brachial artery laceration (*arrows* point to the transacted brachial artery) (**b**). The repair of the artery was performed using an end-to-end reversed saphenous graft (*arrows* indicate the reconstructed brachial artery)

angiography (Swan et al. 2002) or CT angiography (Miller-Thomas et al. 2005). These techniques have proved to be more sensitive than angiography in evaluating peripheral circulation, possibly associated with colour-flow duplex ultrasound. Colour-coded duplex scanning (CCDS) combined with ultrasound velocimetry (UV) is a quick (less than 20 min), non-invasive and reliable technique in the management of these patients (Benedetti Valentini et al. 2013; Weller et al. 2013). The time elapsed between reduction and return of the radial pulse is a crucial factor to avoid severe vascular damage, so the use of CCDS and UV results very helpful to clarify the vascular condition of the hand saving precious time. In a recent study (Weller et al. 2013), patients with a Gartland type III supracondylar humeral fracture treated by closed reduction and percutaneous pinning who still presented no radial pulse after the procedure underwent Doppler ultrasound investigation. The absence of blood flow was confirmed by Doppler, and consequently

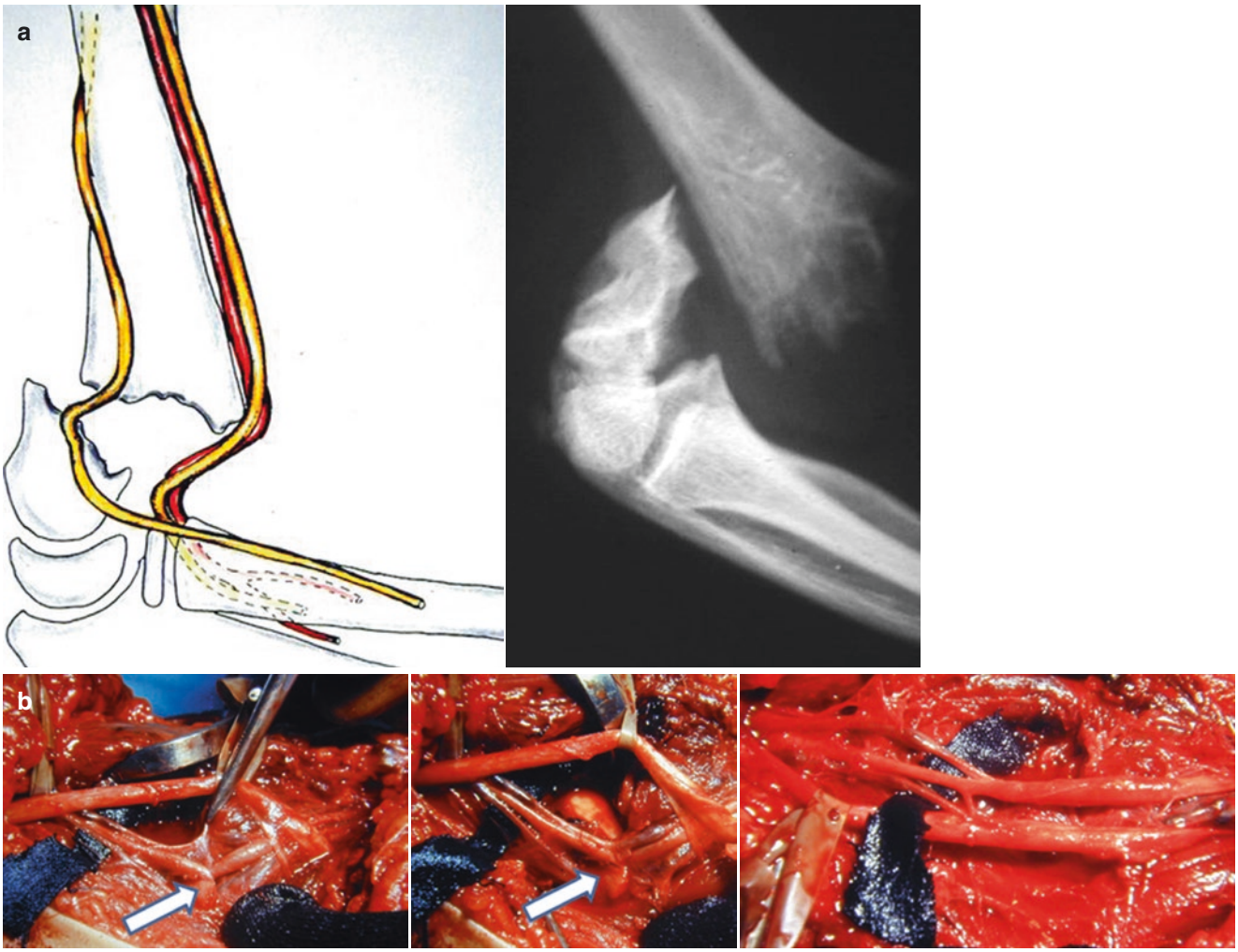


Fig. 24.2 A 14-year-old boy reported a Gartland type III fracture (**a**). After reduction, the radial pulse did not return. The *arrows* show the entrapped artery at surgical exploration (**b**) causing inadequate blood flow perfusion of the hand. Peripheral pulses as well as capillary refill were good throughout the immediate postoperative phase

the patients received open vascular repair, confirming the correlation existing between Doppler and anatomo-pathological findings. The absence of a palpable pulse after closed reduction and percutaneous pinning is not an absolute indication to opt for vascular surgery if the hand is perfused, with a brisk capillary refill, and if the Doppler signal is positive (Weller et al. 2013). In this case, the patients should be carefully monitored postoperatively for 24–48 h (Frick 2013) with frequent observations of their neurological and vascular status. Open surgery can be avoided if during this period they do not show any progressive neurological deficits, increased distal swelling or any change in the perfusion state. Uncertain cases should be further investigated, whereas patients with no radial pulse detected with Doppler ultrasound should be considered for surgical exploration.

Many factors may influence the final result of fractures and/or elbow dislocations with vascular injuries; clinical findings should be carefully evaluated and correlated with information obtained by instrumental assessment (Fig. 24.3).

At surgical exploration the brachial artery can be found kinked with an associated spasm which may sometimes respond to local treatment. Nevertheless the majority of the cases require repair of the damaged lumen removing the thrombus and using urokinase infusion. If end-to-end anastomosis is not possible, the brachial artery should be reconstructed using an interposition saphenous vein graft (Noaman 2006) (Fig. 24.1b).

The brachial artery must have adequate length to permit full extension of the elbow. If perfusion of the forearm and hand has been poor due to prolonged ischaemia, forearm fasciotomy should be done during vascular repair to reduce compartmental pressure, thus preventing Volkmann's contracture (Mubarak and Wallace 2000). The sequelae of an untreated vascular injury are devastating ranging from Volkmann's ischaemic contracture to other complications



Fig. 24.3 Algorithm for the management of elbow trauma associated with vascular complications

such as cold intolerance, neurologic deficits or muscle stiffness (White et al. 1996).

24.3 Compartmental Syndrome of the Elbow

Acute compartmental syndrome (ACS) has been recognized since 1881 when Volkmann first described the contracture of the hand caused by excessive pressure within muscle compartments (Mubarak and Wallace 2000; Volkmann 1881). ACS can result from a number of different injuries, including fractures (especially open), crush injuries, vascular problems, burns and, rarely, infections; it may be iatrogenic in nature, due to casting complications or intravenous infiltrations (Kalyani et al. 2011). The final common pathway of ACS is excessive pressure within muscle compartments, which leads to impaired perfusion. If not treated, impaired perfusion may cause myonecrosis, contracture, neurologic dysfunction and eventually long-term disability (Prasarn and Ouellette 2011). Early identification and treatment of ACS has been associated with a decreased incidence of complications and improved outcomes (Dente et al. 2004).

24.3.1 Diagnosis

Early warning signs for ACS include significant swelling, paraesthesias and pain out of proportion to the injury. Paraesthesia and tingling may occur as an early symptom (as early as 30 min from the onset of ischaemia) in acute compartmental syndrome, representing a potentially reversible state because the peripheral nerves are more sensitive to ischaemia than muscles (Matava et al. 1994). It is thought that irreversible ischaemic changes begin approximately 8 h after the onset of ischaemia. Diminished pulses, pallor and progressive neurologic deficits are late findings that are less commonly seen. The standard diagnosis includes pain out of proportion to what is anticipated from the clinical situation, weakness of muscles in the compartment, pain on passive stretch of the muscles of the compartment, hyperaesthesia in the distribution of nerves going through the compartment and tenseness of the compartment envelope (Matsen et al. 1980). Because the arterial supply of the arm is unique, with a particularly good collateral circulation, gangrene and critical ischaemia are rare in the upper limb. However, it is crucial to diagnose ACS at an early stage to eliminate its preventable complications. Compartmental syndrome of the upper limb can result in different degrees of tissue damage, ranging from temporary impairment to total loss of function of bones, muscles, nerves, skin and soft tissues. The muscles undergo infarction with the formation of muscle sequestrum (Fig. 24.4); this is followed by a central area of necrosis with subsequent fibrosis, leading to the shortening of the muscle and deformity. The consequences of a missed diagnosis are serious, including rhabdomyolysis and renal failure, long-term motor and sensory deficits, amputation and possibly death (Mubarak and Wallace 2000). Particular attention should be paid in the presence of injury to the median or ulnar nerves, or both, since pain and tenderness may be minimal or absent even in the presence of a developing or established compartmental syndrome. The normal pressure of a tissue compartment falls between 0 and 8 mm Hg (Klenerman 2007). Clinical findings associated with ACS generally correlate with the tissue pressure within the affected compartment:

- Capillary blood flow becomes compromised when tissue pressure increases to within 25–30 mmHg of mean arterial pressure.
- Pain may develop as tissue pressure reaches between 20 and 30 mmHg.
- Ischaemia occurs when tissue pressure approaches diastolic pressure.

These values are approximations; the pressure necessary for injury varies depending upon clinical circumstances. Higher compartment pressures may be necessary before injury occurs to the peripheral nerves in patients with systemic hypertension, while ACS may develop at lower pressures with hypotension or peripheral vascular disease (Szabo et al. 1983). Direct measurement of compartmental pressure may help diagnosis (Fig. 24.5), but it does not provide significant values for either sensitivity or specificity (Janzing and Broos 2001). Standard guidelines for decompression include absolute pressure readings above 30 mmHg (Mubarak and Owen 1977). However, perfusion of the compartment depends on the difference between the diastolic blood pressure and the compartment pressure, known as ΔP. If the difference



Fig. 24.4 The muscle undergoes infarction with the formation of muscle sequestrum followed by a central area of necrosis with subsequent fibrosis

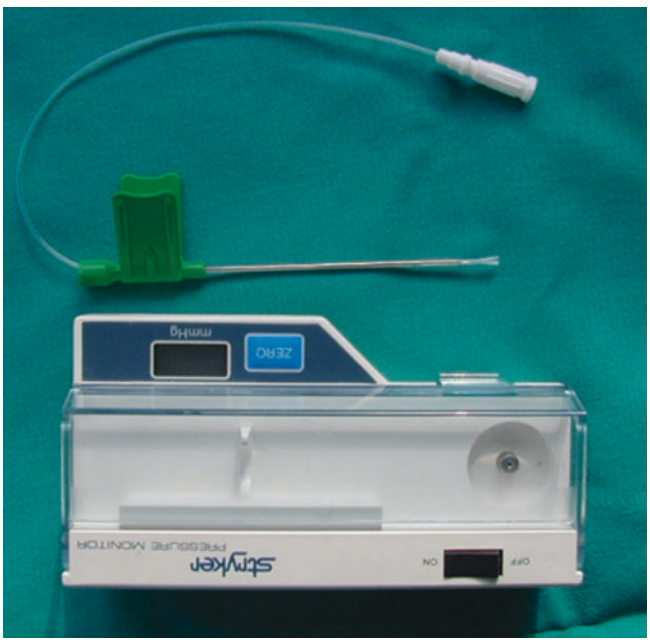


Fig. 24.5 Stryker manometer for pressure measurements

between the diastolic or mean arterial pressure and the compartment pressure falls below a specific value, perfusion pressure becomes compromised and ACS can develop. In addition, many believe that the use of absolute pressure measurements can be misleading (White et al. 2003); therefore the most commonly used approach is to consider a difference between the diastolic blood pressure and the compartmental pressure (delta pressure) of 30 mmHg or less as the threshold for diagnosing ACS (Whitesides et al. 1975).

In summary:

- ACS delta pressure = diastolic blood pressure − measured compartmental pressure.
- ACS delta pressure between 20 and 30 mmHg indicates fasciotomy.

This is a reliable indicator; however it should be emphasized that it needs to be considered in conjunction with the overall clinical condition of the patient.

24.3.2 Invasive Pressure Measurement

In 1975 Whitesides described the measurement of compartmental pressure by direct determination of interstitial pressure (Whitesides et al. 1975). Although multiple techniques for the direct measurement of compartmental pressure have been described (Mubarak and Owen 1977; White et al. 2003; Whitesides et al. 1975; Willy et al. 1999), three are the most frequently used. They may employ a hand-held manometer (e.g. Stryker device) (Fig. 24.5), a simple needle manometer system and a wick or slit catheter. Both manometer methods involve injecting a small quantity of saline solution into a closed compartment to measure the resistance of the tissue, although the hand-held manometer method is most frequently used because it is portable, simple and accurate. The slit catheter technique involves inserting a catheter into the compartment to monitor the pressure by means of a transducer connected to a pressure amplifier. Whichever the method used to measure compartmental pressure, accuracy depends upon proper calibration of the measuring device and placement of the needle or pressure sensor close enough to the site of fracture or injury. The forearm has four compartments: the deep and superficial volar compartments, the dorsal compartment and the lateral compartment. The volar compartments contain the flexor tendons, while the dorsal compartment contains the extensor tendons. The volar compartments are at highest risk for developing ACS following trauma. The most frequent injuries associated with ACS in the forearm are the supracondylar humerus fractures in children and the distal radius fractures in adults (Kalyani et al. 2011; Whitesides et al. 1975). In the forearm, the junction of the proximal and middle thirds is an appropriate location for needle insertion. To measure the compartmental pressure, the needle is inserted 1–2 cm ulnarly to the palmaris longus tendon in the volar compartments or radially to the border of the ulna in the dorsal compartment. A rise in pressure during the passive extension of wrist/fingers or external compression of the volar forearm or during passive flexion of the wrist/fingers or external compression of the dorsal compartment indicates that the needle reached the correct depth.

24.3.3 Non-invasive Techniques

Non-invasive imaging techniques for determining intracompartmental pressure have been also suggested including near-infrared spectroscopy (NIRS), ultrasonic devices and laser Doppler flowmetry (Harvey et al. 2012). NIRS measures local soft tissue oxygenation approximately 2–3 cm below the skin, and it could provide continuous monitoring for intracompartmental hypoxia (Cole et al. 2012).

24.3.4 Chronic Exertional Compartmental Syndrome

Compartmental syndrome ranges from acute to late. Chronic exertional compartmental syndrome (CECS) is a condition in athletes caused by repetitive loading or exertional activities. The pathophysiology of CECS is related to a marked increase in tissue pressure within the confinement of a closed fascial space during exercise. Muscle volume can increase up to 20% of its resting size during exercise. Increased muscle volume determines an increased internal pressure within the fascial compartment (Shah et al. 2004). CECS is characterized by exercise-induced pain relieved by rest. In some cases, weakness and paraesthesia may accompany the pain. The most common conservative method consists in discontinuing the activity that elicits the symptoms or decreasing the intensity of training. If athletes cannot obtain relief from conservative measures or desire to continue competition, a compartmental fasciotomy is the treatment of choice.

24.3.5 Causes of Acute Compartmental Syndrome

24.3.5.1 Fractures

Several studies showed that fractures are the most common cause of ACS, accounting for about 69–75% of cases (Erdos et al. 2011). It is important to remind that, contrary to the common belief, there is no difference between the ACS of open and closed fractures (McQueen and Court-Brown

1996). Many surgeons believe that open fractures naturally decompress the compartment and may not be as prone to develop compartmental syndrome as closed fractures. The small fascial tears that usually result from open fractures do not adequately decompress the compartment.

24.3.5.2 Paediatric Supracondylar Fractures

Supracondylar fracture of the humerus is a common injury in children associated with a number of well-known complications, one of the most feared being the compartmental syndrome of the forearm (Blakey et al. 2009; Rasool and Naidoo 1999; Lyons et al. 2000; Choi et al. 2010; Mehlman et al. 2001; Schoenecker et al. 1996; White et al. 1996; Sabharwal et al. 1997; Blakemore et al. 2000). The pathophysiology leading from an increased compartmental pressure to muscle ischaemia is debated, although it likely includes a combination of arterial spasm, small vessel collapse and increased venous pressure. Current changes in the management of supracondylar fractures with wide acceptance of percutaneous pin fixation and cast immobilization with an elbow flexion <90° resulted in a significant decrease in supracondylar fracture-related compartmental syndrome.

24.3.5.3 Associated Fractures of the Forearm and Elbow

In the study conducted by Hwang et al. (2009), the prevalence of compartmental syndrome was 15% in patients with an unstable distal radial fracture and a concomitant unstable elbow injury. Based on their findings, Hwang et al. concluded that patients with the combination of an unstable fracture of the distal end of the radius with an elbow injury show a higher risk of developing a compartmental syndrome than patients with an isolated unstable fracture of the distal end of the radius. The ipsilateral elbow injury may act as a "second hit" (Roberts et al. 2005) that elevates compartmental pressures above a critical threshold, increasing the risk of compartmental syndrome from 0.3 to 15%. Ring et al. (Ring et al. 2001) noted that in a group of ten children with a floating elbow injury treated with closed reduction and plaster immobilization, two had compartmental syndrome and four had incipient compartmental syndrome.

24.3.5.4 Elbow Dislocation

The elbow is the most commonly dislocated major joint in the paediatric population (O'Driscoll 2000). One of the most important roles of the emergency physician with individuals presenting with elbow dislocations is the evaluation for concomitant neurovascular injuries. The elbow is divided into two compartments: anterior and posterior. The anterior compartment contains the brachial artery, the median nerve and the ulnar nerve. During dislocation, the distal part of the humerus can cause direct injury to the brachial artery and the nerves within the anterior compartment of the elbow. Failure to identify injuries with a thorough neurovascular examination both before and after reduction of the elbow dislocation can potentially lead to severe morbidity with limb ischaemia, neurologic changes, cold intolerance, compartmental syndrome and potential loss of the limb (see previous Sect. 24.2).

24.3.5.5 Brachial Vessel Injury

It is possible to identify the following three major independent risk factors correlated with the development of ACS and consequent need for fasciotomy: significant intraoperative blood loss, presence of open fracture and concomitant arterial injury. Serial physical examination and aggressive pressure monitoring with a low threshold for fasciotomy should be considered (see previous Sect. 24.2).

24.3.5.6 Other Factors

Another potential iatrogenic aetiology for compartmental syndrome is the use of tourniquets. Tourniquet syndrome, which represents a reperfusion injury, can occur if tourniquet time exceeds 120 min and provokes pallor, swelling and stiffness. Signs and symptoms are typically limited to 1 week and may be prevented by reducing the time of tourniquet use in the operating room or, during longer cases, taking 30-min breaks to allow for intermittent reperfusion (Townsend et al. 1996). Finally, casting, dressings or ill-fitting compression stockings can also lead to compartmental syndrome in orthopaedic patients (Danner et al. 1989). To minimize the risk, splints or bivalved casts should be used for all patients with significant swelling or injuries associated with compartmental syndrome.

24.4 Management

Immediate management of suspected ACS includes relieving all external pressure on the compartment. Any dressing, splint, cast or other restrictive coverings should be removed. The limb should neither be elevated nor placed in dependent position. Placing the limb level with the heart helps maintain the arterial inflow and reduce compartmental pressures. Analgesics and supplementary oxygen should be provided. Timely fasciotomy to fully decompress all involved compartments, thus reducing morbidity, is the treatment of choice for ACS in the majority of cases (Fig. 24.6). Fasciotomy is usually performed using the standard technique, with an incision extending from the biceps tendon to the palm of the hand, with or without decompression of the carpal tunnel. Carpal tunnel decompression should be performed when the clinical symptoms and signs indicate median nerve suffering with intraoperative persistent severe swelling of the distal end of the forearm and wrist. A fascial incision allows a thorough inspection of the flexor compartment muscles. If this



Fig. 24.6 Volar forearm fasciotomies using a volar curvilinear incision in a case of severe electric-burn injury

does not provide adequate decompression, an extensor compartment release can be performed through a direct dorsal incision. Inadequate decompression is defined as a persistent swelling in the dorsal compartment despite the release of the volar compartment and/or persistently raised intraoperative compartmental pressures. Fasciotomy is occasionally not indicated. For instance, it should be avoided when the muscle is already dead; fasciotomy in such cases provides no benefit and may even increase the risk of infection. In specific low-risk circumstances, fasciotomy may not be necessary, but this decision should be taken by the surgeon. Hyperbaric oxygen was described as an adjunct treatment for ACS (Wattel et al. 1998), but further research is needed to determine whether its role is clinically significant or not.

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Peripheral Nerve Entrapment Syndromes at the Elbow

25

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25.1 Introduction

Several peripheral nerves cross the region of the elbow joint, having close relationship with its anatomical structures (canals, aponeurosis, muscles) (Clavert et al. 2009; Sivak et al. 2016). Congenital variants, intense physical activities (like in sport or heavy jobs), and posttraumatic or iatrogenic anatomical anomalies are the cause of entrapment in this region. Similar to all the other entrapment syndrome, the incidence at the elbow increases in patient with general conditions that increase the vulnerability of the peripheral nervous system (diabetes, hypothyroidism, kidney chronic insufficiency) (Kim et al. 2016; Macaré van Maurik 2015). There are five nerves of the upper limb at the elbow level: the three main trunks (Fig. 25.1) are the median and radial nerve in the anterior compartment and the ulnar nerve in posterior groove of the medial humeral condyle. There are two thin sensory branches that can cause an entrapment syndrome mainly because of fibrosis of forearm fascia (postsurgical). The first is the radial superficial sensory branch, and the second is the lateral cutaneous nerve of the forearm, which is a terminal branch of the muscle cutaneous nerve (Andreisek et al. 2006).

25.2 Nerve Structure

The nerve fibers or axons are peripheral extensions of the cell body (soma) located in the anterior horn of the spinal cord (motor neurons), in the dorsal root ganglion (sensory neurons) or sympathetic ganglia (sympathetic neurons).

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The main component of the peripheral nerve is the connective tissue which constitutes the skeleton, scaffolding the axons and Schwann cells. Connective has also protective and nutritive function.

The area occupied by nerve fascicles, compared to that occupied by epineurium, and epineurium perifascicular, varies from nerve to nerve and for each nerve varies depending on its level: for example, nearly 85% of the sectional area of sciatic nerve at the level of the hip consists of connective tissue (Sunderland 1968).

The outer cover of the nerve is given from epineurium, connective tissue containing collagen and elastic fibers, resulting in continuity with what wraps the fascicles, called interfascicular epineurium, and the inner resulting more soft of outer epineurium.

The fascicles vary both for number and for size, depending on the type of the nerve and the anatomical level at which it is examined. Each fascicle is surrounded by the perineurium, which consists of collagen fibrils scattered between the perineurium cells, similar to Schwann cells for some common characteristics such as the presence of the basal lamina.

The perineurial cells have tight junctions, so the perineurium is an important station of the blood-nerve barrier: an interruption of the perineurium can impair the function of axons, whose conductive properties are reduced and in some cases demyelination and reduction of their caliber may occur (O'Brien 1987; Otani et al. 2016; Qi and Che 2015).

The perineurium is crossed by vessels that carry with them the connective tissue that joins with endoneurium that surrounds axons; the capillary endothelium is a second blood-nerve barrier, together with endoneurium. An alteration of the permeability of these vessels is found frequently even after relatively light nerve trauma or compression (Rydevik et al. 1981; Rydevik et al. 1976; Rydevik and Lundborg 1977).

The nerve structure consists of the axons and the Schwann cells.

Schwann cells surround the axons in their course and form the myelin sheath. At the junction, between two Schwann cells, the axon is "naked": this is the Ranvier node, which allows an ion exchange between axoplasm and extra-

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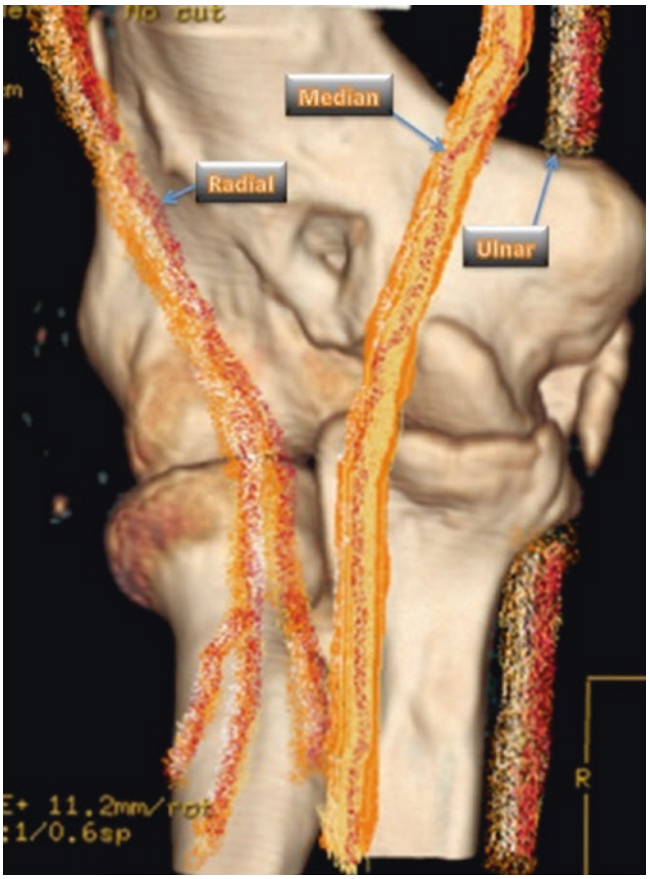


Fig. 25.1 3D CT scan reconstruction showing the relationship between nerves and bony anatomy

cellular space, and it makes possible saltatory nerve impulse conduction type. In smaller and less myelinated fibers, the impulse conduction along the axon occurs more slowly.

25.3 Pathophysiology of Nerve Compression Injury

The nerve damage due to a compression situation is commonly called *nerve entrapment*. This definition is related to an anatomical situation in which there is a disproportion between the volume of peripheral nerve and the space within the territory through it passes (Tang et al. 2015). The entrapment can be caused by a fibrous or fibrous-osseous tunnel through a muscle, fascial edge, blood vessels, or also by a fibrotic outcomes of a fracture (Bouche 2013; Andreisek et al. 2006). Important anatomical features of peripheral nerve, in the pathophysiology of nerve compression injury, are the relative amounts of connective tissue as are epineurium and perineurium. Another determinant condition is the size and the topography within nerve of the fascicles and nerve fibers. Large fascicles with a small amount of epineurium are probably more vulnerable to compression than small fascicles embedded in a large amount of epineurium (Arnold and Elsheikh 2013; Dahlin et al. 1986a; Erlanger and Gasser 1937; Fowler and Ochoa 1975; Gasser and Erlanger 1929; Sunderland 1968). The topography of intrafascicular fibers of the nerve seems also to be important; fibers located near the surface of the fascicles suffer more than fibers located centrally (Aguayo et al. 1971; Powell and Myers 1986; Spinner and Spencer 1974).

The peripheral nerve health is critically dependent on blood intake. The early microvascular changes in nerve entrapment that are induced within the nerve are a very significant factor. External pressure of 20–30 mmHg induces a slowing of venular blood flow in the epineurium. Compression at 60–80 mmHg induces complete circulatory arrest in compressed nerve segments (Myers et al. 1986; Rydevik et al. 1976). This alteration leads to ischemia of the nerve segment that can be rapidly reversible or result in more severe damage if the cause of compression has not been removed. The axonal transport is affected by low-pressure levels, and this is significant in the nerve damage. The nerve compression syndrome may affect anterograde and retrograde axonal transport. Compression of peripheral nerve at 20–30 mmHg can induce a block of intracellular neural transport. The circulation of intramural microvessels is restored after 6 h of ischemia with little or no thrombus formation. Longer periods of compression as 8 h or more are followed by a no reflow phenomenon in fascicle, and it is associated with important endoneurial edema and irreversible loss on nerve function (Aguayo et al. 1971; Powell and Myers 1986; Spinner and Spencer 1974). The endoneurial edema can cause an increase in endoneurial fluid pressure. Each of the events that occur in peripheral nerve during compression contributes to deterioration of nerve function during and following high pressure compression (Schmid et al. 2014). Unmyelinated nerve fibers are more resistant to compression than myelinated fibers. This probably is due to the fact that large fibers are subjected to greater deformation than thinner fibers at given pressure level. Smaller myelinated fibers also seem to resist compression better than large fibers (Dahlin et al. 1989; Dahlin et al. 1986b).

Chronic nerve compression can lead to ultrastructural changes in myelinated fibers as a progressive detachment of myelin sheath with retraction of myelin along internodes and corresponding accumulations of excess myelin along the opposite side of internodes (Ochoa 2012, 1980a, b) (Fig. 25.2). In the advanced damage appears a pronounced perineural and epineural thickening of the nerve and functional/structural alteration of nerve cell bodies.

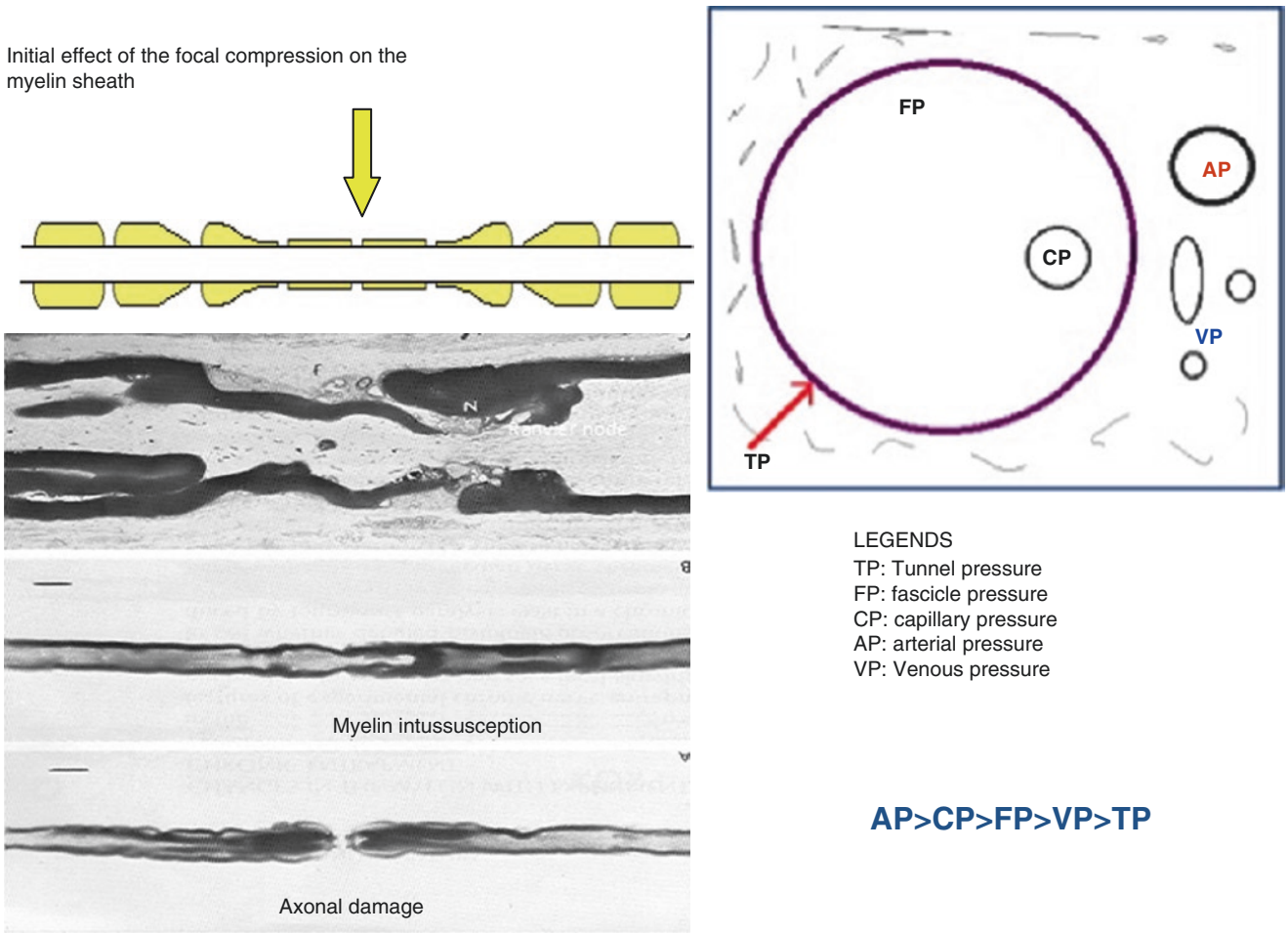


Fig. 25.2 *Left*: the microanatomy of the nerve fiber under compression. Different degrees of damage responding to increased efficacy of the compressive agent. *Right*: the Sunderland (Staffa 2012) rule to prevent fascicular edema

In the pathophysiology of nerve entrapment, it's important to consider pre-existing conditions that make peripheral nerve more susceptible to damage from nerve compression trauma: diabetic neuropathy, chemotherapies, congenital predisposition, and particular activity. It appears that these features make peripheral nerves more vulnerable (Jang et al. 2014; Moon et al. 2014; Okuhara et al. 2014; Rota et al. 2014).

25.3.1 Ulnar Nerve

The ulnar nerve is originated by the fusion of C8 and T1 nerve roots, and it merges at the axilla as terminal branch of the medial cord of the brachial plexus. At the elbow the nerve becomes superficial, laying behind the medial intermuscular septum. It enters a sort of groove that commonly is called *cubital tunnel*. Around the elbow the ulnar nerve runs posteriorly to medial epicondyle in a space in which the floor is the posteromedial side of humeral-ulnar joint and the anterior bundle of medial collateral ligament (MCL). The roof is made by a fascial bridge, spanning the olecranon and medial epicondyle, called Osborne band or ligament (it was described for the first time in 1957 (Osborne 1957; Gross and Gelberman 1985; Dy and mackinnon 2016). More distally the nerve runs in an area in which it lies on sublimis tubercle (site of distal insertion of MCL) and under the deep fascia of the two heads of the flexor carpi ulnaris muscle (FUC). So the fibro-osseous component is formed by the ulnar groove of the medial epicondyle proximally and the joint capsule and medial collateral ligament distally (MCL) (O'Driscoll et al. 1991).

At the elbow the fascicular anatomy of the ulnar nerve is extremely variable; however Sunderland found that the motor fibers to the intrinsic muscles of the hand and sensory fibers to the hand were more superficial than the motor fibers to the FCU and flexor digitorum profundus (FDP) to the fourth and fifth fingers. This condition may explain the relative sparing of FCU and FDP function in compression of the ulnar nerve at the elbow (Sunderland 1968).

25.4 Congenital Conditions

It's quite common to see at the anatomical exploration congenital condition that can justify the nervous entrapment. The most frequent are the valgus elbow, the unstable nerve (luxating during the flexion), and the increased thickness of the Osborne band. Rarely the cause can be related to other anomalies as the anconeus epitrochlearis muscle or a low-lying or prominent medial triceps muscle (snapping triceps syndrome).

25.5 Acquired Conditions

The cubital tunnel syndrome may be related to specific mechanical causes such as occupational factors, elbow osteoarthritis, and direct trauma to the elbow.

Hypoplasia of the fascial roof of the cubital tunnel has been related to increased risk of ulnar nerve subluxation and nerve dysfunction (Boland et al. 2007).

Degenerative affections of the joint, such hypertrophic osteoarthritis, can alter the anatomy of the medial side of humeral-ulnar joint (osteophytes) (Fig. 25.3). In this condition the nerve is compressed by the inner side. Typically, in this kind of compression, neurological symptoms are elicited from hyperflexion and pronation of the elbow, so the nerve is squeezed between the joint bony surface and the Osborne ligament.



Fig. 25.3 Osteophytes in the posterior part of the medial epicondyle engulfing the ulnar nerve in the cubital canal

The medial instability of the elbow due to acute or chronic damage of medial ligaments can lead to a complex syndrome in which articular and nerve sufferance are combined. This pathology is frequently related to sport activity, and their treatment requires a combined approach to fix at the same time the instability and decompress the nerve.

In many cases of cubital tunnel syndrome it is impossible to find an anatomical favoring condition or an acquired situation. This case has defined idiopathic nerve entrapment.

25.6 The Cubital Tunnel Syndrome

The cubital tunnel syndrome is the second most common compression neuropathy of peripheral nerve after carpal tunnel syndrome in the upper extremity. Although the nerve can be compressed in several points along its course, in most of the cases, it occurs at the elbow. The anatomical course of ulnar nerve exposes it to a damage (Mahan et al. 2015).

Clinically the onset is represented by paresthesia at the last two fingers of the hand; rarely it occurs at night (or at least the nociceptive input is not able to awake the patient). Patients don't complain about pain. This clinical stage usually is not recognized by the patient, and he comes to the specialist for observation when the lesion signs are already defined. These are characterized by abnormal sensations or numbness on the fourth and fifth finger (more on fifth), on the ulnar side of the palm, and the back of his hand. This aspect is particularly important, because it distinguishes a "high" ulnar lesion (at the level of cubital tunnel) from a "low" ulnar lesion (at the Guyon canal at the wrist). Anatomically the ulnar sensory branch that is distributed to the dorsal portion of the hand comes out 4–6 cm above the pisiform bone and thus is not affected by a distal compression at the wrist as in Guyon syndrome.

The ulnar nerve has a specific function for the hand, complementary to the median nerve that is responsible for gentle grip.

The ulnar function is the "power grip." The first deficit disorders occur when the patient must make efforts as opening a can and turning a handle, a screwdriver, etc.

In the evolution of nerve compression, the fifth finger is no longer able to clamp into adduction to the other and, even later, is held detached from the fourth (when the patient puts his hand in his pocket, this finger remains out). The focal deficits of fourth interosseous revealed early by the imbalance that causes the integrity preserved extensor (common and just the little finger, which have an abductor function). At this time appears the *Froment sign*, consisting in the impossibility to hold a paper between the fingers fourth and fifth adduced. The *Tinel sign* at the elbow is positive. In advanced stage the hand begins to change its aspect: atrophy of the first dorsal interosseous muscles is the early sign of

muscle degeneration, followed by atrophy of all the intrinsic muscle of the hand with the exception of the thenar eminence. The weakness of the third and fourth lumbrical muscles, which extend the proximal interphalangeal joint, creates an imbalance between the flexor and extensor of the last two fingers resulting in the attitude called "claw" (Bouche 2013).

In some patient the Osborne ligament can be substituted by a muscle that is called "epitrochlearis muscle." The presence of this anatomic anomaly can be the reason of medial pain in throwing athletes (Fig. 25.4).

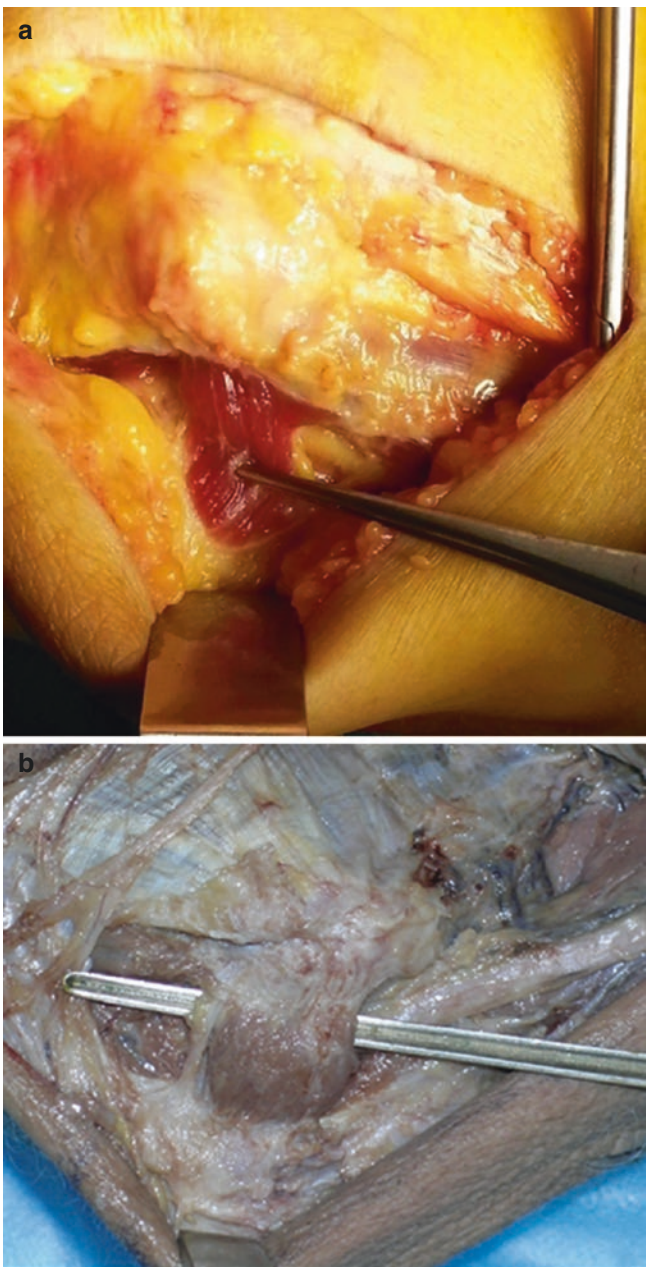


Fig. 25.4 Anconeus epitrochlear muscle, anatomic anomaly, can be found in place of Osborne ligament. (**a**) Surgical finding. (**b**) Cadaveric specimen

The diagnosis is possible with the clinical finding, and the knowledge of the risk factors, but it should ever be confirmed by the electrophysiological examination. At the elbow there is a physiological drop in motor conduction velocity, from 60 ms above the elbow, to 40 ms in the wake olecranon-epitrochlear, to return to 50 ms below the elbow (measured values at elbow flexion). Electrophysiological data are very reliable for the canalicular syndrome showing the slowdown below 40 m/s for the motor conduction velocity above and under the elbow (Bauwens 1960). Most of the entrapment conditions are due to compression in the distal part of the cubital tunnel. The canal is closed distally by the double origin of the flexor carpi ulnaris. This output in the flexion of the elbow tends to decrease the space for the nerve.

25.7 Technical Notes

If the surgical planning is to transpose anteriorly the nerve, the skin incision can be posterior to medial epicondyle to avoid damaging sensitive branches of medial antebrachial cutaneous nerve. In the case of decompression, the skin incision should be done anterior to the epitroclea, to avoid scar encasement of the nerve by overlaying wound. Anyway it's possible to make an anterior, "bow"-shaped, incision to avoid damaging the two branches from medial cutaneous of the forearm. In the case of transposition, the nerve can be mobilized to the new submuscular canal, sliding under the intact sensory branches.

25.7.1 Ulnar Nerve Decompression

This procedure is usually indicated in nerve entrapments of mild or moderate severity. It's not recommended in recurrence of the pathology or in case of anatomical deformities (congenital or post traumatic).

The nerve is generally identified proximally to medial epicondyle by palpation. The anatomical landmark is the medial intermuscular septum. For every technical choice, we recommend in revision surgery to detect the nerve proximally (or proximal to previous sites of surgery), because finding the nerve at joint level can be very challenging for fibrous tissue.

The nerve must be handled very gentle sparing all the vascular supports. There are two main arterial branches for the nerve supply in this region. The first is proximal to the elbow and it's easy to identify beneath the intermuscular septum. It follows the nerve longitudinally for 1 or 2 cm penetrating it 1 cm before the entrance in the canal. This vessel can be gently mobilized allowing the transposition without the need to damage it. The second is distal at the

level of the branching to the extensor carpi ulnaris. This artery can be damaged during the splitting of the two head of the muscle. Finally there is a small vascular support in the midway of the tunnel that can be sacrificed for the transposition, but it should be preserved in the decompression.

We proceed by making neurolysis from proximal to distal. Osborne ligament or anconeus epitrochlearis muscle must be sectioned. Dissection of the nerve must carry on opening the two head of FUC and both the superficial and deep fascia of the muscle. At this point branches for FUC are visualized, they can be variable ranging from 1 to 6 (Marur et al. 2005), and they are anterior to ulnar nerve. Consequently, if the neurolysis is made staying posteriorly to the nerve, the risk of damaging FUC branches is decreased. Martin-Gruber variation can be present in 14–34% of patients: it's a communicating nerve anastomotic branch between the median nerve and the ulnar nerve (Zayane et al. 2011). Excessive mobilization of the nerve must be avoided. If all the constrains of the nerve are released, it can become unstable. Authors suggest only decompress the "roof" of the cubital tunnel, carefully, from proximal to distal, not cutting constrains between the "floor" of groove and the nerve.

25.8 Ulnar Nerve Transposition

Transposition is necessary when the nerve is unstable or stretched in his anatomical position or if the anatomy of the cubital tunnel is strongly compromised (Macadam et al. 2008). Orthopedics and neurosurgeons' ways to address the ulnar nerve when transposed are different (Assmus et al. 2011).

Orthopedics generally transpose the nerve in subcutaneous tissue, after an around 15 cm release and a careful resection of intermuscular septum. This step is very important to decrease to risk of compression: the septum (if not resected) can create a kinking of the nerve proximally. A subcutaneous pouch to lay the nerve is prepared detaching subcutaneous layer from the flexor-pronator fascia. Sensitive branches must be protected in this phase. A flap of fascia can be engraved (from distal to proximal, leaving the fascial insertion on the medial epicondyle intact); this flap can be sutured to the subcutaneous tissue to avoid nerve slipping back in extension (Fig. 25.5). The advantage of subcutaneous transposition is that the nerve can be easily detected for possible further surgical procedures. The disadvantages are that it can be surrounded by fibrous tissue and becomes more superficial, so the risk of microtrauma is higher. During the flexion of the elbow, the nerve should be relaxed, but during the extension could be compressed and stretched.

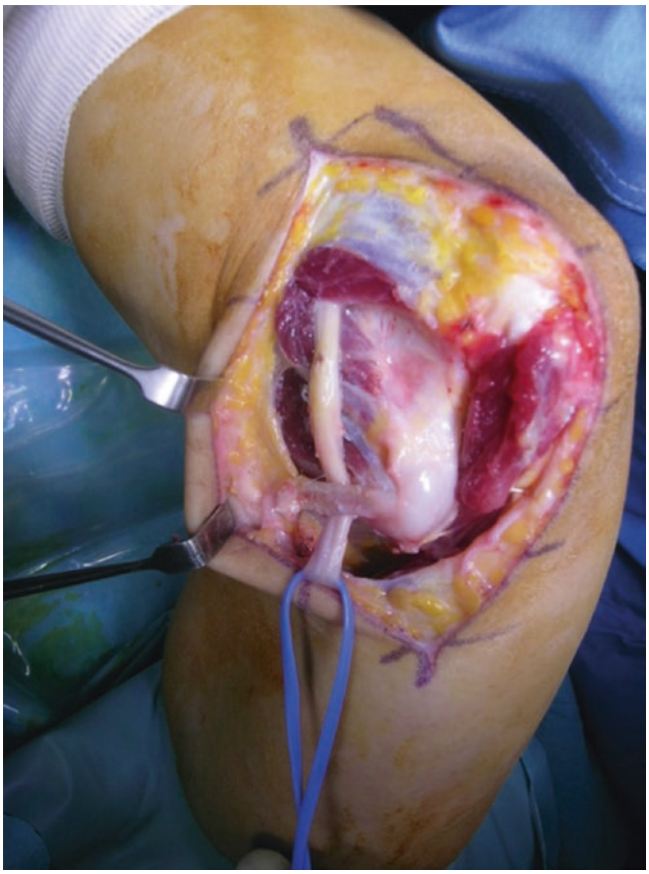


Fig. 25.5 After medial head rerouting and ulnar nerve subcutaneous transposition. A fascial (from flexor-pronator fascia) flap is used to secure the ulnar nerve from slipping back

Neurosurgeons prefer to transpose the nerve submuscularly. They cut the flexor-pronator group (up to the brachial muscle and the median nerve), and they lay the nerve on the articular anteromedial capsule. The advantages are that the nerve is hidden by the muscle; this can also increase its potential blood supply. In this position the extension of the elbow doesn't modify, as the flexion the nerve compartment. There are two disadvantages: first, future arthroscopic procedures are relatively contraindicated because the anteromedial portal can damage the nerve (Jacobson et al. 2010) and, second, the postoperatory management includes 20 days of immobilization and this can lead to elbow stiffness.

Of course the submuscularis transposition is contraindicated if the elbow is unstable. Flexor-pronator muscle is secondary medial stabilizer of the elbow in valgus stress, and, if there's a previous valgus instability (torn medial collateral ligament), the instability pattern get worse.

Some paper reports decreased rate of complications but increased incidence of recurrence with subcutaneous transposition (Liu et al. 2015a, b).

25.8.1 Conclusions

In situ ulnar nerve decompression is indicated if the nerve is squeezed by Osborne ligament, anconeus epitrochlearis muscle, or deep ulnar carpis flexor aponeurosis. If the nerve is unstable or if the retrocondylar groove is anatomically incorrect, transposition is necessary. Valgus instability is a contraindication to submuscular transposition. Authors think that a debate between orthopedic and neurosurgeon must precede surgical treatment, and a multidisciplinary approach to address ulnar nerve pathology is advocate in most complex cases.

25.8.2 Snapping Triceps

Clinical pattern is characterized by a medial snap during elbow active and passive flexion. The snap is related to an anomalous slip of medial head of the triceps on the medial epicondyle (Fig. 25.6). In some instances a double snap can be appreciated: in those cases the first snap is the snapping ulnar nerve that is pushed forward by the triceps muscle, and the second snap is related to the muscular snap. The snap can be elicited also by active extension against resistance around 90° of flexion. This pathology can cause ulnar nerve symptoms. The surgical technique must address both the triceps medial head (reshaping and rerouting the oversized muscle on olecranon insertion) and the ulnar nerve; if the ulnar nerve is still unstable in flexion, after muscular plasty, it must be transposed (Morrey 1985).

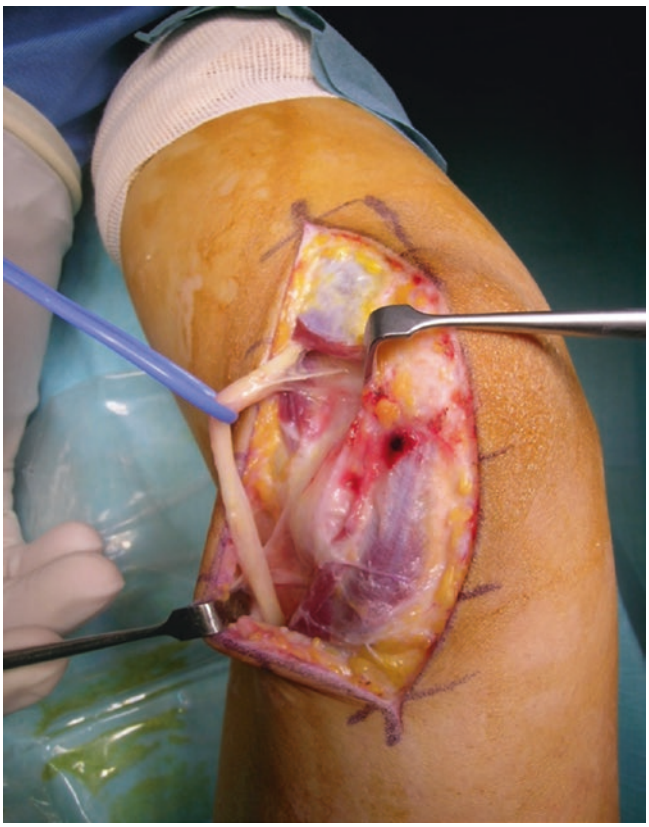


Fig. 25.6 Snapping triceps: the medial head of triceps exceeds the medial epicondyle. Ulnar nerve is dissected and unstable

25.9 Median Nerve

The entrapment of the median nerve at the elbow rarely occurs (Jang et al. 2014). Often the entrapment conditions are related to congenital anatomical varieties or acquired pathological conditions of the joint at distal humerus.

More often the responsibility of the nerve damage can be due to mechanical conditions like instability or asymmetric joint overloading (throwing athletes).

More frequently the median nerve can be compressed distally to the joint in the pronator canal. Also in this condition, hypertrophy of muscle belly or muscular hyperactivity (like racing bikers and tennis players) can be the reason of compression.

25.10 Congenital Conditions

The anatomical varieties that can produce median nerve compression are:

- Proximally to the elbow: Struthers arcade (Suranyi 1983)
- At the elbow: hypertrophic lacertus fibrosus (Fig. 25.7)
- Distally to the elbow: at the pronator canal (pronator teres syndrome) and at the sublimis flexor arcade (anterior interosseous nerve palsy) (Pham et al. 2014) (Fig. 25.8)

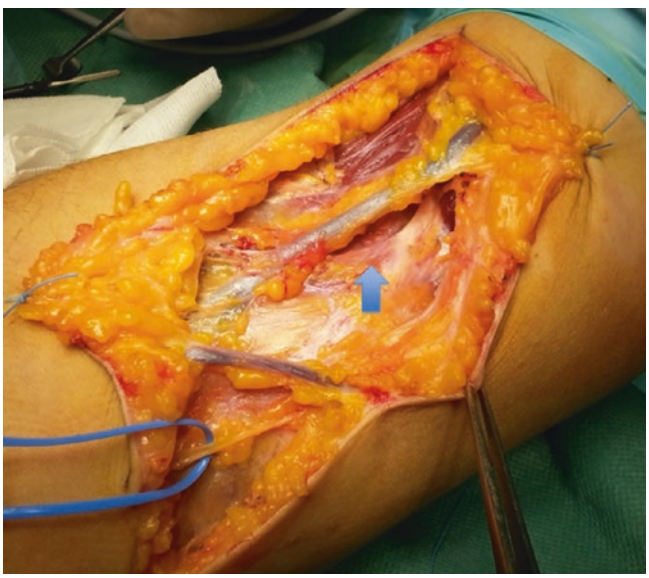


Fig. 25.7 Thickening of lacertus fibrosus (*arrow*) can compress the median nerve proximally to pronator teres

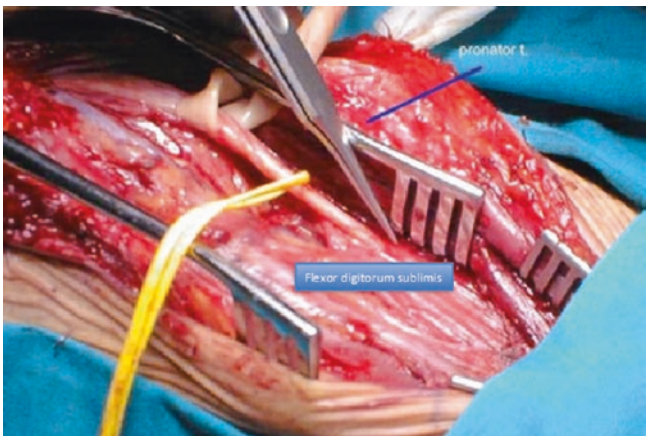


Fig. 25.8 Surgical dissection of median nerve (*yellow loop*) and its potential sites of compression: pronator teres and flexor superficialis digitorum arcade

25.11 Acquired Conditions

Frequently the involvement of the median nerve at the elbow, due to pathological condition following acute or chronic trauma, is associated to ulnar nerve lesions. Common causes are hypertrophic bony callus and heterotopic ossification (Fig. 25.9). Rarely the median nerve can be entrapped into the joint or can be encased by the hypertrophic bony tissue after fracture of medial epitrochlear. The instability of the elbow can promote the development of fibrous tissue or thickening of the biceps tendon creating compression and conflict with the nerve, proximally to the pronator canal.

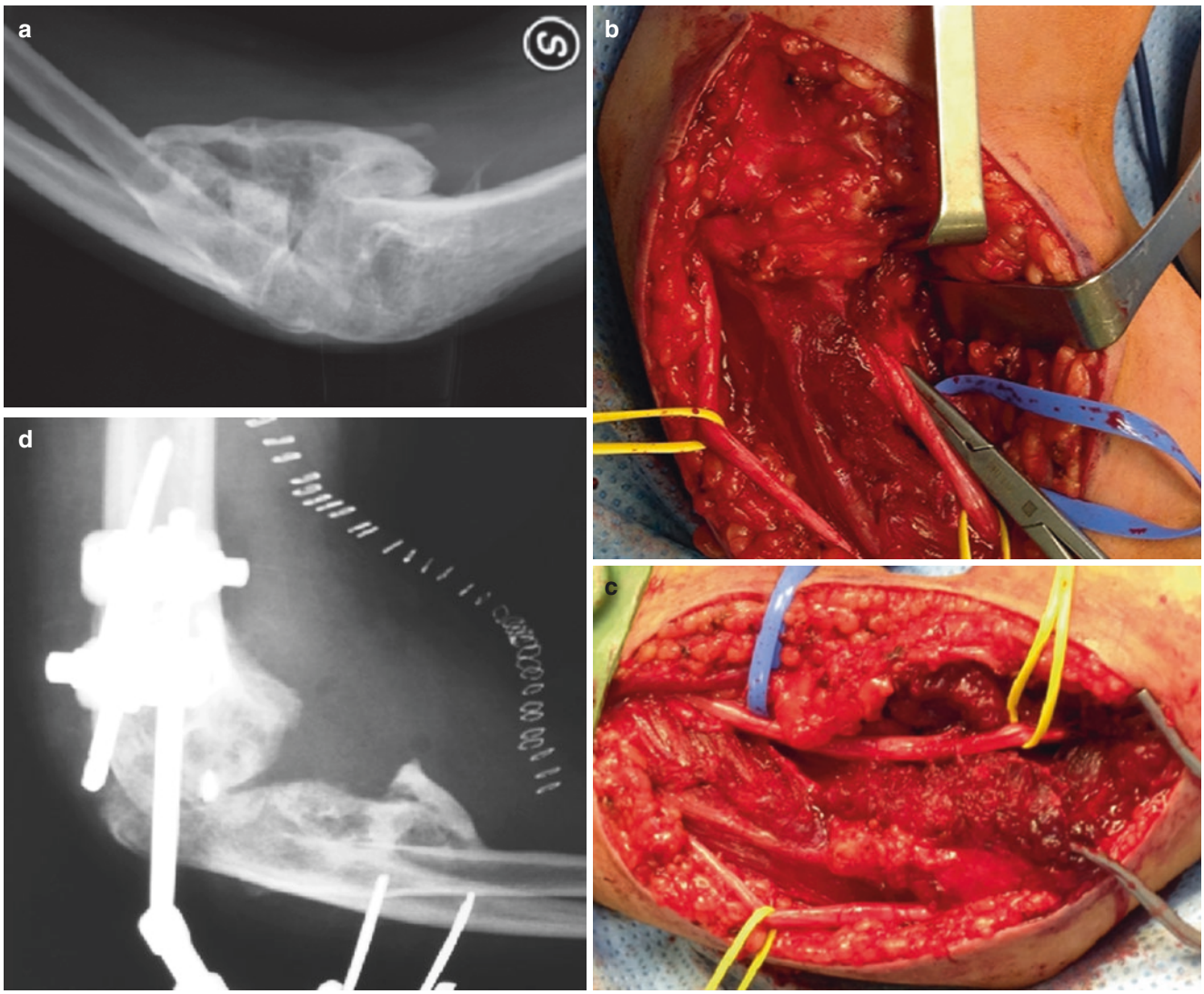


Fig. 25.9 (**a**) XR rays showing posttraumatic massive heterotopic ossification span from humerus to ulna. (**b**) Intraoperative findings: the median nerve is encased by ossification. (**c**) After ossification removal. (**d**) Postoperative XR with external fixator to keep the elbow reduced after ligaments reconstruction

25.11.1 Pronator Teres Syndrome (PTS)

The pronator teres syndrome is the most common compressive pathology of the median nerve at the elbow. The anatomical site is the canal between the superficial and deep heads of the pronator teres (PT) muscle. This space has different conditions related to the position of the forearm (pronosupination). The cross section of the canal is circular during supination. When the forearm is pronated, the superficial head of the muscle squeezes the nerve against deep head, and the anatomy of the canal changes from a tubular to a ribbonlike compartment. The compression may be due to a hypertrophic pronator teres muscle (athletic syndrome) (Katerina et al. 2015; Lee et al. 2014).

Patients complain neurological disorders and signs related to median nerve involvement distal to the innervation of the pronator teres (Fig. 25.10). The median nerve, distally to the pronator teres muscle, provides innervation to the anterior interosseous nerve (AIN) which innervates the flexor pollicis longus (FPL), pronator quadratus (PQ), and flexor digitorum profundus (FDP) muscle to the index and middle finger.

Differential diagnosis between PTS and more proximal median nerve entrapment is clinically and electromyographically possible, testing the PT muscle. If the nerve is suffering at the Struthers ligament or at the lacertus fibrosus, most probably the PT innervations will be compromised. In moderate syndromes the electrical studies could be unhelpful, and negativity of these tests doesn't exclude the syndrome when the clinical findings are suggestive (mainly when job conditions or sports are favorable elements).

Early symptom of the pronator syndrome is a vague pain at the forearm. Other findings are numbness and tingling in the first three fingers of the hand, Phalen test negativity, weakness and eventual atrophy of the intrinsic muscles dependent on the median nerve, and Tinel positive at the level of the pronator teres. This is helpful in differential diagnosis with carpal tunnel syndrome (CTS). The former usually involves the function of flexor profundis to the second and third finger and flexor pollicis longus. These clinical findings are never recorded in CTS. A characteristic sign of the weakening of the flexor pollicis longus and the flexor digitorum profundus is highlighted by the circle test that is performed by asking the patient to make a circle with the first two fingers opponing the tip of the thumb against the index finger. Another characteristic feature is the loss of strength in forearm pronation maneuvers, due to weakening of the square pronator muscle. Anyway it is difficult for the beginner to distinguish the pronation sustained by the PT instead of square pronator. Clinically, the physician questions for a history of pain and value for tenderness in the region of the proximal volar elbow, specifically in the area of the pronator teres. The pain can be considered an important symptom in making the diagnosis and also to determine the level of injury. In the PT syndrome the pain is exacerbated when patient pronates the forearm against resistance and simultaneously extends the elbow; instead if pain is evoked during activation of flexor digitorum superficialis, the site of pathology is most probably distal to the pronator canal. If pain is elicited in elbow flexion and supination of the forearm against resistance, median nerve is trapped by bicipital aponeurosis.

This clinical findings is generally incomplete. When a patient has a condition related to a posttraumatic hematoma involving the area of bicipital aponeurosis, the clinical exam-

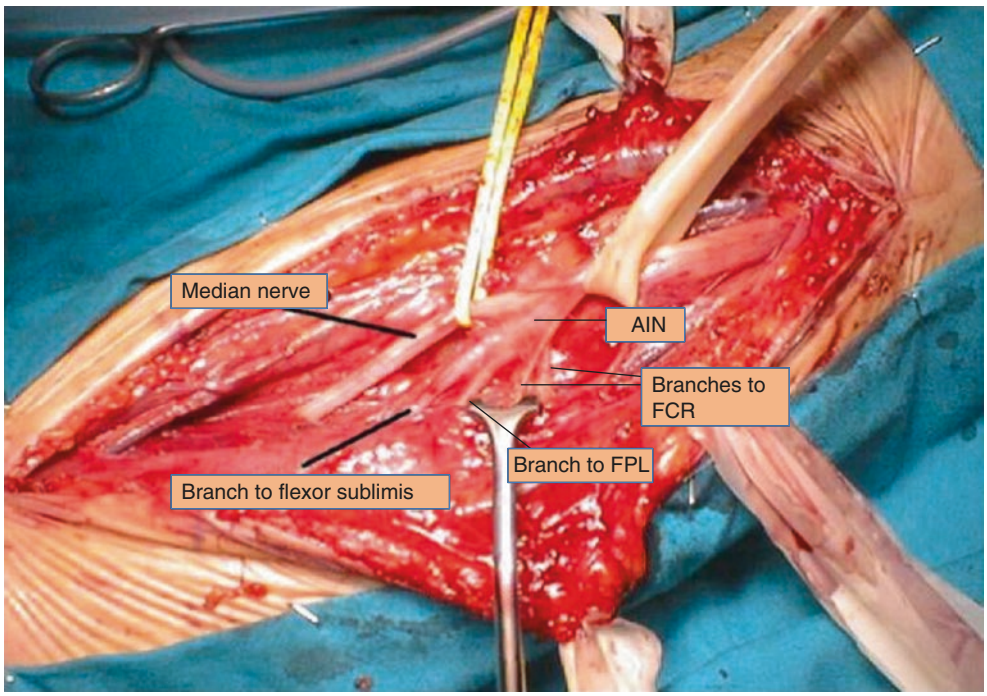


Fig. 25.10 Anatomical dissection of median nerve: the median nerve, distally to the pronator teres muscle, branches flexor carpi radialis (FCR) leave the nerve proximally to the anterior interosseous nerve (AIN)

ination can be variable, related to the evolution of the clots. At the beginning we can see a proximal compression, like a lacertus fibrosus syndrome, and, after weeks, it modifies to a pronator teres or AIN syndrome.

Other conditions that should be excluded in differential diagnosis are thoracic outlet syndrome (TOS), C5–C6 cervical radiculopathy, and syringomyelia.

Despite of the different level of compression, in all the surgical cases, the exploration of the nerve should be extended from the lacertus fibrosus to flexor digitorum superficialis arch.

25.11.2 Technical Notes

The skin incision should be in a Z way on the volar side of the elbow. The first landmark is the biceps tendon and its connection (bicipital aponeurosis to the lacertus fibrosus). The median nerve is easily identified anterior to medial intermuscular septum, proximal to the lacertus fibrosus at the distal third of the arm. The lacertus fibrosus is opened, and the brachialis artery, crossing laterally the median nerve, should be dissected and protected. The external neurolysis of the nerve is performed until the entry zone of the pronator canal. The supination of the forearm can provide wider space for the dissection of the nerve, between the two heads of the PT. The detachment of the superficial head of the PT is rarely necessary. In this case the surgeon should avoid the partial dissection of the PT superficialis because of the risk of recurrence due to the scarring fibrous tissue. If the surgeon decides to extend the procedure until the onset of the anterior interosseous nerve, the two bellies of the pronator teres should be spread apart to expose the fibrous band which represents the arcade of the superficial flexor of the fingers. In this area we have several branches from the main trunk of the median nerve. The first one is deputed to the deep head of the PT; 2–4 cm distally, we have several branches for the superficial head of the PT and for the flexor carpi radialis. The nerve divides in two main trunks: the bigger and more superficial is the principal and terminal branch of the median nerve directed to the hand, and deeper the smaller one entering beneath the flexor superficialis arcade is the anterior interosseous nerve (AIN). To have a complete decompression of the nerve, we have to follow the anterior interosseous nerve for at least 2 cm distal to the flexor superficial arcade that should be widely opened. In this area, as in the pronator canal, the median nerve and the AIN can be crossed by venous vascular loops that should be accurately coagulated and divided.

25.11.3 Radial Nerve

The radial nerve crosses the anterior and lateral compartment of the elbow. In most of the patients, the sensory branch traces along with the radial nerve but is anatomically separable from it several centimeters above the elbow joint with great variability of the branching. For this reason the anatomical exploration of the radial nerve in this area can show different variants according to the onset of the radial sensory branch from the main trunk. In most of the cases, the sensory branch is superficial compared to the radial trunk and lays under the fascia, in the cleft between the proximal brachioradialis muscle belly and the brachial muscle (Fig. 25.11). It is necessary to move deeper and split the fibers of the brachioradialis muscle to palpate the nerve and to expose the main trunk of the radial nerve. The first motor branch, deputed to motor innervation on the brachioradialis muscle, merges 2–3 cm above the head of the radius bone. At the level of the head of the radius bone, there is the onset of the braches to the long supinator muscle and the extensor carpi radialis. Distally the nerve turns deep and laterally in the anatomical canal between the deeper surface of the long supinator and the lateral edge of the extensor carpi radialis (giving sometimes other innervation to these muscles). Three to four centimeters below the articular edge of the radial head the radial nerve become the posterior interosseous nerve (PIN) and penetrates the extensor muscles compartment passing under the arcade of Frohse.

The radial nerve at the elbow can produce two different entrapment syndromes:

- The PIN syndrome
- The radial tunnel syndrome

25.11.4 Posterior Interosseous Nerve (PIN) Syndrome

The PIN passes through the radial tunnel. The floor of this anatomical space is formed by the deep head of the supinator and the capsule of the radiocapitellar joint, while the roof is formed by the superficial head of the supinator and the radial recurrent vessels (Bionka Huisstede et al. 2006; Fernandez et al. 1998; Portilla Molina et al. 1998). The posterior interosseous nerve enters the radial tunnel underneath a musculotendinous arch, the arcade of Frohse (Clavert et al. 2009; Kinni et al. 2009) (Fig. 25.12). The arcade of Frohse, which is the most common point of compression, is a connection between the deep and superficial heads of the supinator and is fibrotendinous in 30% of the population. The PIN continues in the radial tunnel through the supinator, as it goes from the anterior to the posterior surface of the forearm. The radial nerve supplies the majority of the forearm and hand extensors (Alexander 2003; Fernandez et al. 1998).

The posterior interosseous nerve is a motor nerve and sequentially innervates extensor digitorum communis, extensor digiti minimi, extensor carpi ulnaris, abductor pol-

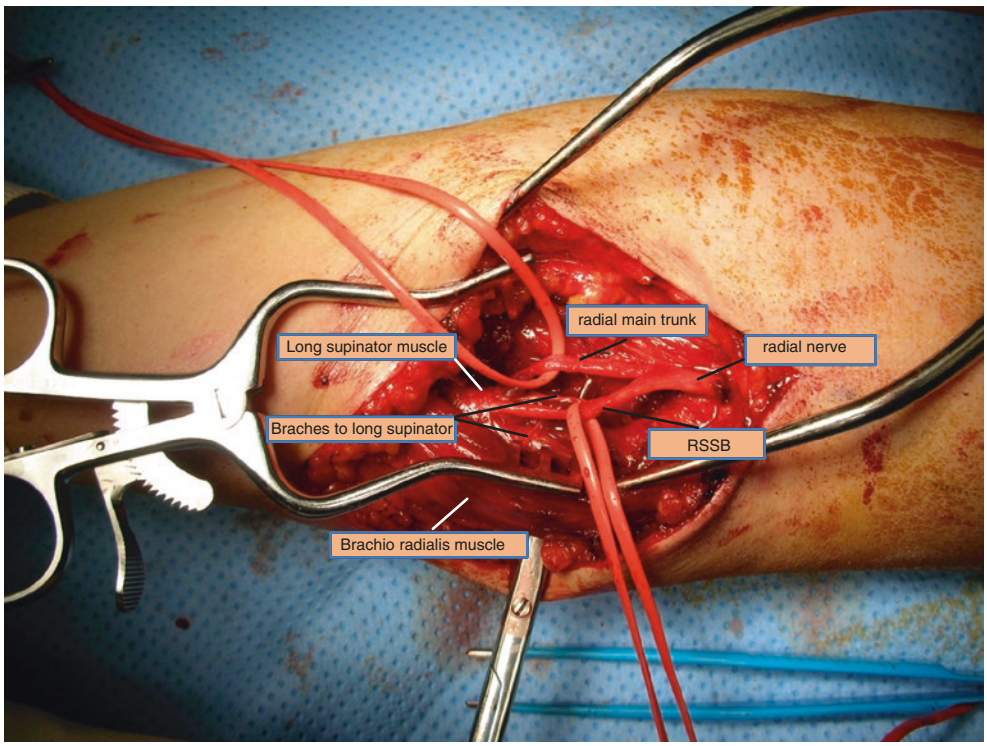


Fig. 25.11 Anatomical dissection of radial nerve in the proximal part of the radial tunnel: radial superficial sensory branch (RSSB)

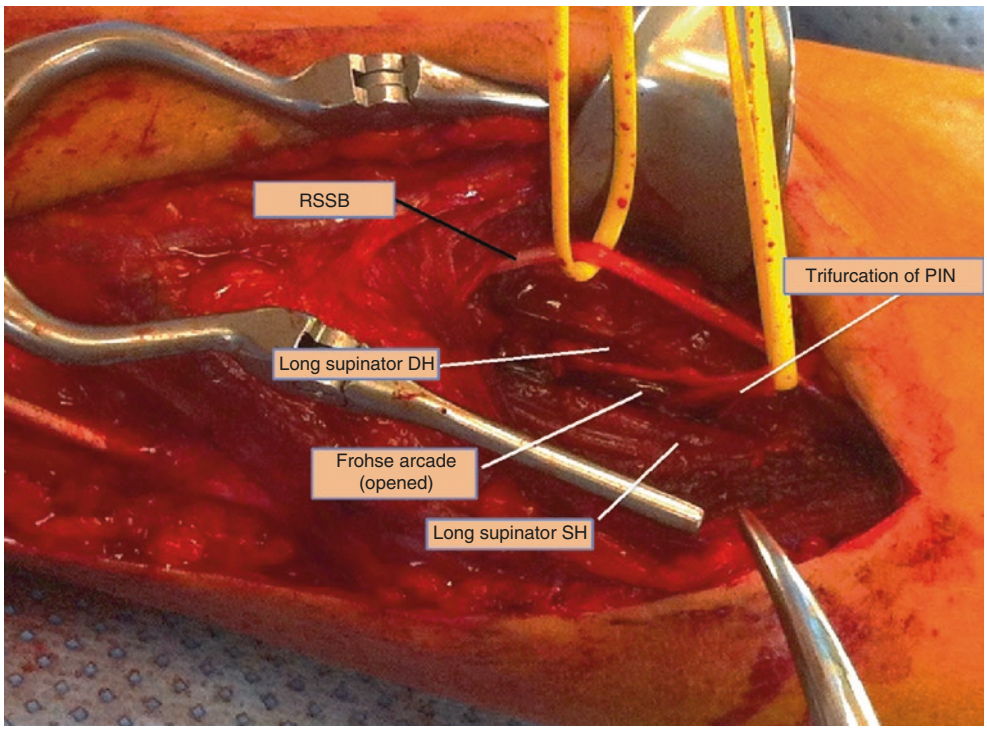


Fig. 25.12 Posterior interosseous nerve (PIN) at the end of the cubital tunnel. The arcade has been partially opened to show the trifurcation of the PIN. *DH* deep head, *SH* superficial head

licis, extensor pollicis brevis, extensor pollicis longus, and extensor indicis.

Damage to the PIN results in a posterior interosseous nerve syndrome. The syndrome may result in paresis or paralysis of the digital and thumb extensor muscles. The paresis may be complete or partial, and in both cases the onset may be associated or not to pain at the elbow or proximal forearm; often the onset is acute. Patient is unable to extend the thumb and fingers at their metacarpophalangeal joints. The only movement the patients may be able to do is the radial extension and the supination of the wrist. A posterior interosseous nerve syndrome usually develops spontaneously and is caused by a compression of the arcade of Frohse due to anatomical variants, like fibrous band, vascular loops, and thickening of

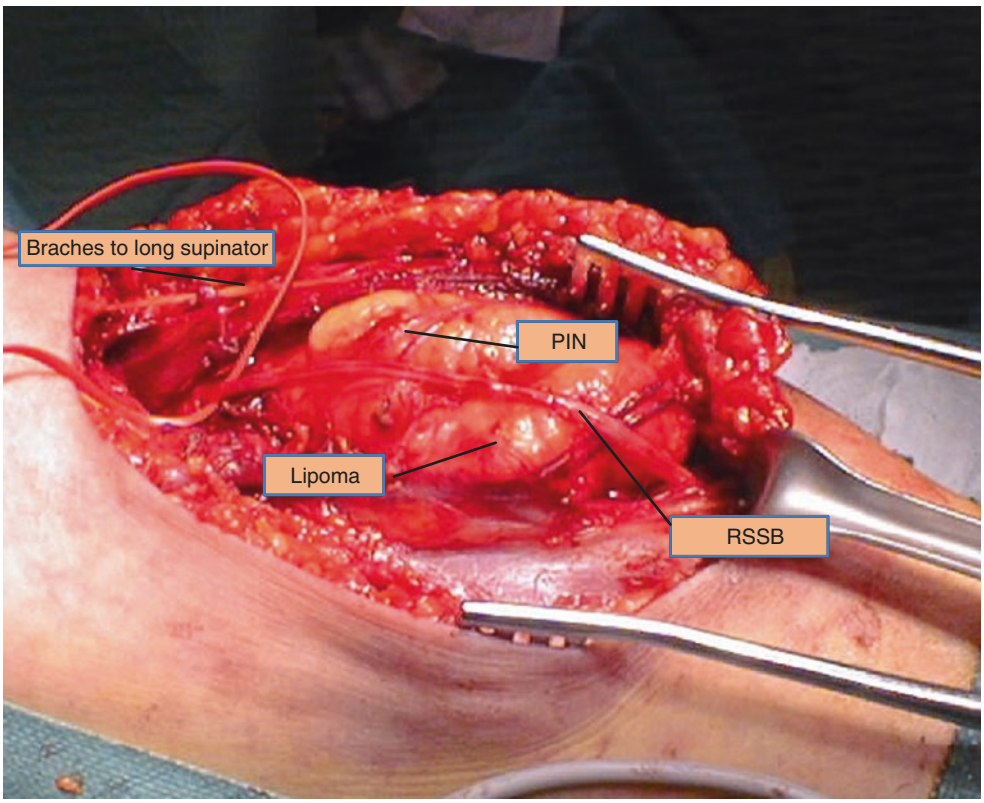


Fig. 25.13 Severe compression and dislocation of the radial nerve branches due to a huge lipoma growing from the interosseous membrane

the Frohse edge. A favorable condition is hyperactivity of trigger muscles, like supinators, as in sports activity (tennis, squash, body fitness). Repeated pronation and supination can produce a dynamic compression of the nerve in the proximal part of the forearm (Morrey 1985; Portilla Molina et al. 1998).

Entrapment can be caused also by a traumatic injury (fibrosis after surgery of the radial head) that can have modified the dimensions or elastic properties of the radial canal and tumors (lipoma of the interosseous membrane) (Dietz et al. 2016) (Fig. 25.13).

25.12 Clinical Presentation

Most nerve entrapments usually are due to an osseoligamentous tunnel narrowing. In the case of a posterior interosseous nerve entrapment, the compression occurs within the musculotendinous radial tunnel. In 2/3 of patients the nerve is compressed by the fibrous arcade of Frohse.

Symptoms of nerve entrapment syndromes are generally involving pain, sensory and motor changes, sensations of popping, paresthesias, and paralysis. The PIN syndrome is mainly characterized by motor deficits. The absence of sensory symptoms can help distinguish a PIN palsy from cervical radiculopathy. The PIN syndrome is one of the pathologies that can cause lateral elbow pain. Some other pathologies that are associated with lateral elbow pain are lateral epicondylitis, radial tunnel syndrome (proximal nerve entrapment without motor or sensory deficits), and cervical radiculopathy (Gilliatt 1970). If the palsy of the nerve is partial, involving only some branches, the clinical complaints can simulate a tendon rupture.

Careful clinical and electrophysiological examination is important and essential for a reliable diagnosis. EMG (electromyography) and NCV (nerve conduction velocity) can help to set the diagnosis. In the preoperative assessment of the patient, the electrophysiological examination can establish the topography of the lesion and the severity of the muscular denervation (Fernandez et al. 1998; Kim et al. 2008).

The diagnosis of posterior interosseous syndrome can be based on the findings of the patients' history and the limitations or deficits that the patient might have during physical evaluation.

In the examination of radial nerve, the first test which can be performed to make a diagnosis is palpation of the forearm: abnormal tenderness is expected over the arcade of Frohse and eventually over the lateral epicondyle.

Second step of the examination is testing five movements in sequence: shoulder depression with the elbow flexed to 90°, forearm pronation, elbow extension, wrist and finger flexion, and the shoulder abduction.

This *neural tension test* should be performed on both upper extremities for comparison. The last evaluation is the power of muscle (with resistance). In radial nerve palsy, the lesion can be partial or complete of the wrist extensors.

Patient is unable to extend the thumb and other fingers of the affected side at the metacarpophalangeal joints.

Dorsiflexion is possible but only with a dorsoradial direction, due to the weakened extensor carpi ulnaris. Resisted supination and pronation of the forearm can produce pain, as well as resisted extension of the middle finger. The brachioradialis, extensor carpi radialis longus, and extensor carpi radialis brevis are innervated by more proximal branches of the radial nerve, so they may be spared.

25.12.1 The Radial Tunnel Syndrome

The radial tunnel syndrome (RTS) is an entrapment syndrome of the radial nerve along the already described anatomical canal. Differently from the PIN syndrome, the compression is usually more proximal and most commonly is due to conflicts with proximal insertion of extensor radialis brevis or the radial recurrent artery. The RTS is characterized by pain in the elbow and forearm without motor weakness or sensory deficits. This entrapment is recognized as one of the cause of tennis elbow syndrome.

The patients with RTS complain tenderness and pain in the lateral aspect of the elbow. Usually the pain radiate distally until the third finger, but without paresthesia or numbness. The pain may increase with motor activity and sometimes is deep and similar to muscle cramps. A provocative test is asking the patient to make extension and supination of the wrist against resistance. This pathology is frequent in motorbike pilots. The intensive and repetitive use of extensor of the wrist and of supinators (use of the throttle) determines the clinical onset. The relationship with the physical activity is so clear that we can consider the syndrome in this patient as a "peripheral nerve claudication syndrome." The pilot experiences the onset of the pain during the race, and the relief of the symptoms begins few minutes after stopping the activity. At the initial level, the pain is localized in the elbow. Insisting with the activity, it spreads along the forearm.

The painful palpation of the nerve course along the medial side of the long supinator muscle helps the differential diagnosis with the tennis elbow in which the pain is obtained pressing the bone of the lateral epicondyle. Asking the patient to fully extend the elbow and the third finger against resistance, we can reproduce the usual pain at the proximal insertion of the extensor carpi radialis brevis. In most of the cases of TRS, the electrophysiological examination is unhelpful for the diagnosis.

25.12.2 Technical Notes

The surgical approach for the two different radial nerve entrapment syndromes at the elbow is similar. Surgical incision for RTS nerve entrapment is more proximal than PIN syndrome. The radial nerve is exposed with an anterior incision "S" shaped along the lateral volar/aspect of the elbow. The radial sensory is identified and protected. The main trunk of the radial is harvested under the brachioradialis muscle, where the nerve pierces the belly of the muscle to enter the cleft between brachioradialis and biceps tendon proximally. At the middle level of the radial tunnel, the nerve lays between the long supinator (lateral and superficial) and the extensor carpi radialis (in the depth and medially). In this part of the route, the nerve gives branches to the supinator and extensor carpi radialis. Here we can frequently find venous loops, sometimes arterial loops (recurrent brachial artery), and in certain cases conflict with the proximal insertion of the extensor radialis brevis. All these anatomical conditions can sustain the painful syndrome called radial tunnel syndrome and in the treatment of this pathology have to be corrected. The entrapment in these cases is mild and particular activities can increase the intensity of the symptoms related. If the patient has a PIN syndrome, the surgical exposition has to be extended in the distal part of the radial tunnel where the nerve enters the Frohse canal. To expose the Frohse arcade, it's better if a gentle traction is done to elevate the supinator muscle showing the connection between the deep and superficial heads of its insertion. This fibrous band has to be opened and the PIN traced distally until its trifurcation. To expose PIN the nerve distally to this level is necessary another approach with an incision at the dorsal radial aspect of the middle third of the forearm. Passing laterally to the long supinator, it's possible to enter the extensors compartment. Combining the two approaches, we can expose the PIN for all its course. The manipulation of distal part of PIN is always complicated by temporary postoperative worsening of the muscular weakness. For this reason should be avoided if not strictly necessary.

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Management of Epicondylitis and Epitrochleitis

26

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26.1 Pathophysiology and Clinical Evaluation of Epicondylitis

Lateral epicondylitis, also known as tennis elbow, is significantly more common than medial epicondylitis (Whaley and Baker 2004) and has an annual prevalence of 1–2% in the general public (Shiri et al. 2006).

As its eponym implies, lateral epicondylitis has a high association with tennis, particularly one-handed backhand strokes. Nearly 40–50% of recreational tennis players will suffer this condition during their lifetime (Mackay et al. 2003; Hume et al. 2006).

This condition, however, is not unique to tennis players. In fact, any sport or occupation that requires repetitive supination and pronation of the forearm with the elbow in near full extension can result in this injury.

In addition to repetitive activities, obesity and smoking (Kurppa et al. 1991; Ritz 1995; Shiri et al. 2006) have been implicated as independent risk factors.

The main cause of lateral epicondylitis is ascribed to degenerative changes in the attachment of the extensor carpi radialis brevis tendon (ECRB) (Calfee et al. 2008; Nirschl and Pettrone 1979; Kniesel et al. 2014; Walz et al. 2010), which is located on the lateral proximal side, covers the radial head, and runs beneath the supinator and extensor carpi radialis longus (ECRL) tendon. Five- to 10-mm distal to its origin from the lateral epicondyle, the ECRB has a biomechanical weak point where it connects to the joint capsule without covering the supinator muscle.

Its occurrence is more frequent in nonathletes than in athletes, with a peak incidence in the early fifth decade and a nearly equal gender incidence.

Lateral epicondylitis does not present with a uniform etiology, but rather can have diverse causes (Calfee et al. 2008; Coombes et al. 2009; Walz et al. 2010). In addition to the mechanical forces that lead to excessive varus stress on the ECRB, its unique anatomic position against the lateral aspect of the capitellum places the tendon at risk for repeated undersurface abrasion during elbow extension (Bunata et al. 2007). The lack of vascularity at the undersurface of the tendon further contributes to degeneration and tendinosis (Bunata et al. 2007).

Although originally described as an inflammatory process, the current consensus is that lateral epicondylitis is initiated as a microtear, most often within the origin of the extensor carpi radialis brevis, although other tendons in the extensor bundle, such as the extensor digitorum communis, may be involved. Microscopic findings show immature reparative tissue that resembles angiofibroblastic hyperplasia, structural failure, and ultimately, fibrosis or calcification (Nirschl and Pettrone 1979; Nirschl 1988). Persistent microtrauma resulting in failed attempts at healing produces tendinosis (Nirschl 1988).

Generally, lateral elbow tendinopathy presents with an insidious onset of lateral elbow pain due to overuse of wrist extensors (Hsu et al. 2012; Ahmad et al. 2013; Hausman and Lang 2014). On examination, there is tenderness to palpation just anterior and distal to the lateral epicondyle at the site of the extensor carpi radialis brevis tendon origin (Hsu et al. 2012; Ahmad et al. 2013; Tosti et al. 2013). The pain can be elicited with resisted wrist extension, middle finger extension

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and forearm supination with the elbow in the extended position (Hsu et al. 2012; Ahmad et al. 2013; Rineer and Ruch 2009). The chair test is positive when lateral elbow pain is reproduced by lifting a chair with the arm in the pronated position (Ahmad et al. 2013; Tosti et al. 2013). Dorf et al. (2007) found that grip strength was 83% accurate in determining the affected from the unaffected elbow in patients with lateral epicondylitis when it was decreased by 8% on the affected side. For a differential diagnosis, consideration must be given to impingement of a radial plica or chondromalacia in the radial compartment, instability, as well as compression of the peripheral branches of the radial nerve and blocked vertebrae. Radial tunnel syndrome (RTS) is a compressive neuropathy of the posterior interosseous nerve caused by structures of fibrous band and vascular variance that cross the nerve. On physical examination, patients with RTS have tenderness to palpation 4–6 cm distal to the lateral epicondyle and pain with resisted supination while the shoulder is adducted and elbow flexed to 90° (Faro and Wolf 2007; Knutsen and Calfee 2013). Posterior interosseous nerve irritation is associated with vague aching in the wrist or forearm that is not characteristic of lateral tendinosis. True lateral epicondylitis and radial tunnel syndrome may coexist in 5% of patients.

A snapping plica can be palpated as the elbow is moved from extension and supination to flexion and pronation (Antuna and O'Driscoll 2001).

Instabilities can develop primarily through the degeneration of the lateral tendon complex, e.g. due to overuse, and secondarily after cortisone injections, surgical removal of the lateral capsular ligament complex, or following injury (Bredella et al. 1999; Geyer 2009; Kalainov and Cohen 2005; Walz et al. 2010). The anatomical role of the individual lateral tendinous and ligamentous structures in stabilizing the elbow has been well examined and described (Charalambous and Stanley 2008; Cohen and Hastings 1997).

Plain radiographs are usually negative; occasionally, calcific tendinitis may be present. To date, in some cases, magnetic resonance imaging (MRI) may be helpful in evaluating the soft tissues of the elbow in patients who have failed appropriate conservative treatment and aids in both diagnosis and surgical planning. Review of MRI findings from 24 patients with epicondylitis reported increased intratendon signal on both T1 and T2 pulse sequences (Martin and Schweitzer 1998) with occasional bone marrow oedema pattern in the epicondyle. Other studies have shown thickening, oedema, and tears of the common extensor tendon (Mackay et al. 2003; Savnik et al. 2004). MRI of patients with lateral epicondylitis and a control population demonstrated intratendinous signal changes in 92% of patients and 16% of controls (Martin and Schweitzer 1998).

26.1.1 Diagnosis

The diagnosis in most cases is clinical pain evoked by digital pressure on the epicondyle and stress resistance against the extensor muscles of the wrist and fingers. The most used evocative tests are Cozen, Mills, and Maudsley tests (Fig. 26.1).

Lateral epicondylitis goes in the DD with cervical radiculopathy, humeroradial arthrosis, lateral synovial plica, compression syndrome of posterior interosseous nerve and lateral instability. The radiographic examination in most cases is negative but allows, at the same time, to exclude comorbid conditions. Ultrasound examination is a method that has low costs and high specificity but lower sensitivity unlike MRI is an investigation that has higher costs and should be reserved for cases in which the clinical condition is strongly suggestive of epicondylitis and the US examination is negative, or in cases of concomitant cartilage damage and ligaments (d'Agostino et al. 2015).

Medial epicondylitis or commonly called "golfer's elbow" is characterized by localized pain in the anterior epicondyle and sometimes even at the level of the pronator teres muscle. Generally joint movement is completely preserved. Evocative tests are positive when the patient reports pain at epicondyle during stress resistance against pronation and flexion of the wrist (Fig. 26.2).

It's really important to look for signs of medial instability subjecting the patient to valgus stress at 30° of elbow flexion as described in literature (Notarnicola and Moretti 2012). It is not uncommon to observe the presence of a concomitant neuropathy of the ulnar nerve up to a 50% of cases, it's important to research the presence of a neuropathy with compression test, Tinel's sign, the elbow flexion test, and ulnar nerve subluxation. There is a classification of medial epicondylitis in relation to the presence and severity of the symptoms of an ulnar neuropathy that distinguishes the type I or medial epicondylitis in patients who presents epitrochleitis without neuropathy and type IIA symptomatic patients without objective deficit and type IIB with clinical deficit and electromyographic (Sistermann and Katthagen 1998). The imaging techniques allow us to confirm the diagnosis and at the same time to exclude pathological conditions that can be confused with medial epicondylitis. Radiographic examination allows to exclude osteoarthritis, calcification at the insertion of epitrochlear muscles and if performed during a valgus stress to confirm or exclude medial instability. US evaluation in case of medial epicondylitis shows similar findings with lateral epicondylitis. The typical findings of medial epicondylitis are cortical irregularity of tendon insertion, tendon thickening, evidence of focal hypoechoic or anechoic areas in the tendon and it's no unusual to find intratendinous calcifications (Rompe et al. 1996, 1997).



Fig. 26.1 (**a**) Cozen test: the extension again resistance of the finger and wrist causes pain on the lateral epicondyle. (**b**) Mills test: pronation against resistance causes pain on lateral epicondyle. (**c**) Maudseley test: the patient refers pain on the epicondyle during the extension against resistance of the third finger. (**d**) Cozen test: the extension again resistance of the finger and wrist causes pain on the lateral epicondyle

Generally we observe these typical changes in the common flexor tendon at the musculotendinous origin of pronator teres and flexor radial carpi muscle.

MRI of the elbow must be reserved for cases of difficult interpretation when there are in association capsule-ligament lesions or in case of reoperations. With concomitant neuropathy of the ulnar nerve is to be completed examination electroneurography.

26.2 Treatments Described in the Literature

Nonoperative management of lateral epicondylitis will result in successful resolution of symptoms in 90% of patients (Hoogvliet et al. 2013a, b; Hay et al. 1999).

Conservative care may include activity modification, nonsteroidal anti-inflammatory medications, physiotherapy,



Fig. 26.2 Pain referred by patient on the medial epicondyle

corticosteroid injections (Smidt et al. 2002a, b), and benign neglect. Tendinitis may occur in the early stage of epicondylitis and may be responsive to anti-inflammatory measures. Later stages represent tendinosis and are less responsive to the same measures. Treatment effect on the condition's natural history, however, remains inconclusive. In chronic lateral epicondylitis, platelet-rich plasma (PRP) has been shown to effectively reduce pain and symptoms in several short-term studies (Gosens et al. 2011a, b; Hechtman et al. 2011; Mishra and Pavelko 2006; Peerbooms et al. 2010a, b; Thanasas et al. 2011a, b).

Activity modification is a necessary component of any treatment protocol, especially given the overuse oetiology of this condition. Patients should be counseled to refrain from inciting activities and motions. Rest, ice, compression and elevation (or RICE) of the affected arm can be helpful during this initial phase. Modifications can be made in technique, such as the use of a 2-handed backhand to reduce the stress encountered by the extensors (Giangarra et al. 1993).

Bracing (forearm straps and cock-up wrist splints) can redirect the extensor force vector and may provide symptom relief (Burton 1985) by reduction in extensor muscle activity (Groppel and Nirschl 1986).

Cock-up wrist splints reduce extensor contraction by limiting wrist flexion and extension allowing the extensors to rest. A prospective randomized study (Garg et al. 2010) comparing the effects of counterforce bracing and cock-up wrist splints at 6 weeks reported superior subjective pain improvement in the splinted group. While the underlying pathology of lateral epicondylitis at the end stage is not inflammatory, the use of non-steroidal anti-inflammatory drugs (NSAID) may be a useful adjunct to activity modification (Burnham et al. 1998). There is a lack of data to support their oral use (Hay et al. 1999; Labelle and Guibert 1997). In contrast, Burnham et al. (1998) noted short-term relief associated with a topical NSAID in their randomized double-blind crossover study.

Physical therapy is another important component to conservative treatment of lateral epicondylitis (Calfee et al. 2008). Traditionally, physiotherapy was aimed at stretching and strengthening the extensors of the forearm (Nirschl 1973).

More current therapeutic modalities include eccentric muscle training (Croisier et al. 2007).

It should be noted, however, that while eccentric training "did not cause subjects to worsen" (Martinez-Silvestrini et al. 2005) there remains limited evidence to support this modality in the elbow over stretching alone.

Corticosteroid injections result in improved short-term patient outcomes, with equivocal results at 12 months. Hay et al. (1999) randomized patients with lateral epicondylitis to three treatment arms (placebo, oral NSAID, and corticosteroid injections). They found that the best short-term (4-week) symptomatic improvements occurred in patients who received the corticosteroid injection, while some improvement occurred in those who received the oral NSAID when compared with placebo. At 1-year follow-up, patient outcomes were similar among three groups.

The efficacy of extracorporeal shock wave (ECSW) therapy remains a source of debate. Three randomized double-blinded studies have reported contrasting results. Pettrone and McCall (2005a, b) reported statistically significant pain improvement at 12 weeks in those treated with ECSW when compared with placebo and concluded that ECSW was a safe and effective treatment for tennis elbow. Two additional studies describe ECSW and placebo as similarly ineffective in treating lateral epicondylitis (Chung and Wiley 2004; Haake et al. 2002).

More recently, injection of PRP has been investigated as a possible treatment. Investigators conducted a trial on patients with chronic lateral epicondylitis, in which 100 patients were randomized to either PRP or corticosteroid injection. Improved pain relief and rates of success in the PRP group were demonstrated at 1 year (Peerbooms et al. 2010a, b) and 2 years (Gosens et al. 2011a, b) post-treatment.

Operative treatment is reserved for patients with refractory symptoms despite 612 months of nonoperative treatment.

The number of patients requiring surgical treatment is given as between 4% and 11% (Boyd and McLeod 1973; Coonrad and Hooper 1973; Verhaar 1994; Nirschl and Pettrone 1979; Kniesel et al. 2014).

Since the beginning of the twentieth century (Hohmann described detachment of the extensor aponeurosis as early as 1927 (Hohmann 1933)), diverse techniques such as percutaneous, arthroscopic, and open surgeries have been described and developed to treat cases with unsuccessful conservative therapy outcomes (Baker and Baker 2008; Baumgard and Schwartz 1982; Bosworth 1965; Calfee et al. 2008; Calvert et al. 1985; Dunkow et al. 2004; Goldberg et al. 1988; Grifka et al. 1995; Grundberg and Dobson 2000; Lo and Safran 2007; Merrell and DaSilva 2009; Nirschl and Pettrone 1979; Owens et al. 2001; Pruzansky et al. 2009; Wada et al. 2009; Wilhelm 2000, 2009).

Surgical repair focuses on debridement of tendinosis and direct repair of the ECRB tendon.

Percutaneous treatment involves release of the extensor tendon origin at the lateral epicondyle. This technique has been advocated as safe, reliable, and cost-effective (Baumgard and Schwartz 1982; Grundberg and Dobson 2000; Kaleli et al. 2004; Yerger and Turner 1985).

Othman reported similar outcomes for arthroscopic and percutaneous techniques at 12 months' follow-up (Othman 2011). Arthroscopic techniques to address recalcitrant lateral epicondylitis involve release of the common extensor tendon. Advocates of this approach cite quick recovery time, including return to work (Baker and Baker 2008) and the ability to evaluate and treat concomitant intra-articular pathology (Lattermann et al. 2010a, b).

Baker and Baker (2008) reported an 87% patient satisfaction rate in 42 patients treated arthroscopically at long-term follow-up (average, 10.1 years).

Over 72–99% good to very good results are reported after carrying out an arthroscopic release and addressing accompanying intra-articular pathologies (Lo and Safran 2007).

Despite the generally positive results, the learning curve, as well as the risk of inadvertent neurovascular injury (Kuklo et al. 1999) or release of the lateral ulnar collateral ligament (Smith et al. 2003) is not insignificant.

On the other hand, Peart et al. (2004) also report 21% of merely satisfactory results and a 7% failure rate. Tseng (1994) reports good results in 9 out of 11 patients; however, the author also reports a complication rate of 33%.

These altogether variable results can be attributed to the difficulty of identifying the extra-articularly located ECRB attachment arthroscopically (Cohen et al. 2008). Two direct-comparison studies of patients treated with open and arthroscopic lateral ECRB release showed similar clinical results (Peart et al. 2004; Stapleton and Baker 1996).

Significant, high quality treatment comparison studies, however, have yet to be published (Buchbinder et al. 2002; Lo and Safran 2007).

Overall, although arthroscopic treatment of lateral epicondylitis is becoming increasingly important, it is also still controversial.

Open treatment involves a small lateral incision with dissection and identification of focus of tendinopathy. The diseased tissue is removed, and decortication of the insertion site on the lateral epicondyle is performed. A suture with anchor repair may be performed of ECRB tendon to bone. Several authors have reported good to excellent results with this approach. Coleman et al. (2010) described a single surgeon's 15-year experience treating refractory cases of lateral epicondylitis. In 158 consecutive patients treated with open technique, 94.6% of patients had good to excellent results at an average of 9.8 years' follow-up.

Dunn et al. (2008) reported their long-term results in 139 cases of tennis elbow with 84% rated as good or excellent, 92% with normal elbow range of motion, and an overall patient satisfaction of 8.9 of 10. Thornton et al. (2005) explored the utility of suture anchor repair of the ECRB tendon to the lateral epicondyle following open debridement of tendinosis. They found normal grip and pinch strength, full range of motion, and near resolution of preoperative pain.

At this time, there are no conclusive results showing which surgical method is most effective in treating lateral epicondylitis. This is mainly due to a lack of high quality studies and the use of no consistent outcome measures (Lo and Safran 2007).

In their detailed review of clinical results, with a synopsis of all postoperative follow-up studies, Walz et al. (2010) report 80% good to excellent results, independent of surgical procedure. However, they also described failure rates that are doubtless familiar to all physicians from clinical practice. Previous studies report a failure rate following surgical treatment, usually defined as no clinical improvement, of between 3% and 20% (Verhaar et al. 1993; Owens et al. 2001; Nirschl and Pettrone 1979).

The incidence of intra-articular pathologies reported in current studies varies considerably between max. 5% (Nirschl and Alvarado 2009) to up to 69% (Baker 2000).

Only a few authors discuss instability as a possible cause of lateral epicondylitis (Geyer 2009). However, several, mainly American, publications on pitcher's elbow have shown that a primary or secondary instability combined with specific loads can lead to lateral epicondylitis as well as changes in the cartilage in the lateral joint compartment (Ahmad and ElAttrache 2009; Sanchez-Sotelo 2009; Kalainov and Cohen 2005; Timmerman and Andrews 1994; Safran et al. 2005).

Especially so far no differentiation was made concerning the possible role of micro instability of the elbow in developing lateral epicondylitis.

Kniesel et al. (2014) have carried out follow-up examinations for 40 patients who received surgical treatment for lateral epicondylitis. Of these, 25 had no instability, 13 had a slight instability and two had severe instability. When instability was arthroscopically detected, patients were treated both for the instability and the debridement of the ECRB tendon. In a direct comparison, the results for patients with instability were not as good as the solely arthroscopically treated group without instability. This could have been ascribed to a more severe underlying disease, as defined by instability caused by degenerative changes.

26.2.1 Surgery Technique Preferred by Author

The decision to use an open or arthroscopic conventional technique depends on the age, the functional requirements and the possible sport. Open surgery is usually reserved for patients who practice manual work is required in which a greater recovery of strength even with longer times, while the arthroscopic treatment is preferred in young patients, sportsmen who need a faster recovery.

Arthroscopy is performed with the patient in the lateral decubitus position, the limb is resting on one side support and the landmarks points are drawn. Through the soft-spot inject 20 cc of saline to distend the joint, then through the anteromedial portal inserting the optical and with outside-in technique is created portal anterior-working side.

Through the anteromedial portal is displayed the anterolateral capsule and displayed the lesion in agreement with the Baker classification.

Through the anterolateral portal is part of a blade scalpel No. 11 and completes the capsular lesion moving in the proximal direction and then with a shaver and proceed to the removal of degenerated tissue capsule and tendon dell'ECRB up to the clear display dell'ECRL tendon and muscle belly of the EDC being careful to never fall under equatorial to the risk of damaging the lateral ligament complex and the LCUL causing then posterolateral instability. With the motorized instrument then goes to do a debridement of the surface epicondyle insertion site dell'ECRB. Routine through other portals you run a diagnostic of the other compartments.

The elbow is then wrapped with a compression bandage.

For the surgical treatment of the medial epicondylitis, the approach that we favour is in open, the patient is positioned supine and straight through skin incision starting from the top edge epicondyle and continuing distally to the same, we proceed to isolation of the ulnar nerve, which is liberated by adhesions or transposed according to the presence or not of a neuropathy. The pathological tissue of the tendon of the pronator teres and flexor carpi radial is removed, taking care not to damage the medial ligament complex. The elbow is then bandaged and immobilized.

26.3 Our Rehabilitation Program

The Department of Morphological, Epidemiological and Clinical Science, Section of Orthopaedics and Traumatology, of Università degli Studi of Pavia (Italy) has reviewed the management approaches to epicondylitis adopted from 1966 to the present. Examination of 185 papers on the treatment of acute epicondylitis led the authors to conclude that there is no scientific evidence for any of the therapeutic methods applied, warranting treatment customization based on patient clinical presentation and functional requirements and on the school and experience of the orthopaedic surgeon. Stahl and Kaufmann studied the effect of lidocaine + cortisone and lidocaine + placebo in a randomized trial involving 60 elbows, and found that in the former group infiltration was associated with pain regression at 6 weeks, whereas cortisone involved no benefit compared with placebo, either at 3 months or at a year. Almekinders and Maffulli (2003) found that only three of eight recent controlled studies reported that corticosteroid injection into the tendon is associated with harmful effects, including tendon rupture. Leadbetter (1992) concluded that these drugs, though useful, should not play a major role in the therapeutic protocol.

In a microscopic study of intra-articular and bursal structures, Nirschl and Morrey (1985) detected fibroblastic tissue and vessel invasion, which prompted the definition of their findings as angiofibroblastic tendinosis and of epicondylitis as lateral tendinosis of the elbow, a condition where degeneration gives rise to abundant fibroblasts, vessel hyperplasia, and disorganized collagen. Tendinosis or tendinopathy implies the absence of chemical inflammation (Almekinders and Mafulli 2003; Waseem et al. 2012). The condition can also be diagnosed by ultrasound alone. However, calcifications in the tendon structure may hamper osteopathic manipulative treatment.

Several physiotherapeutic approaches to epicondylitis have been described. Here we highlight the fact that other healthcare professionals are competent to address it besides the surgeon and the physician, whose approach includes infiltration as first-line (Lee and Lee 2015) and surgery as second-line treatment. Indeed, our experience has shown that osteopathic manipulative treatment is a valuable alternative (Hoogvliet et al. 2013a, b). Patients usually come to the attention of the osteopath or the physical therapist after unsuccessful infiltration or physical therapy. Here they

undergo a very broad assessment that encompasses the tissue condition as well as the subject's homeostatic requirements. Over the years we have learnt the value of a comprehensive evaluation of epicondylitis patients, because assessment of this joint cannot be separate from evaluation of the shoulder, including the scapulothoracic joint, and of the wrist and hand joints, which should all be considered as pertaining to a single segment. Such comprehensive approach to patients and an emphasis on the close interconnections existing among aponeuroses, or fasciae, have enabled us to achieve satisfactory outcomes. Discussion of the holistic approach to epicondylitis requires a brief description of the arm fascial structures that are involved in osteopathic manipulative treatment. The arm aponeurosis encompasses the whole upper limb, not merely the elbow, and is continuous with the cervical aponeurosis, or cervical fascia.

26.4 Upper Limb Fascial Structure (Paoletti 2003)

26.4.1 Cervical and Brachial Aponeuroses

The clavicle connects the scapulohumeral region to the chest anteriorly. It is a key structure, because it connects shoulder and arm, it closes and opens the upper thoracic outlet (UTO), it is subject to visceral influences through the first rib, and since it inserts into the sternum it is also subject to tension coming from it. The arm aponeurosis is continuous with the superficial cervical fascia. As it extends down the arm it connects with the spine of the scapula, the clavicle, and the acromion. It is also continuous with the fasciae of the axillary pit, the latissimus dorsi, and the pectoralis major. It is thicker on the side of the extensors than of the flexors. It is divided into aponeurosis of the shoulder, of the arm, of the forearm, and of the hand.

The complexity of the arm fascia accounts for the close ties existing among the connected structures and for how a pathological condition of one joint can involve the other, connected joints.

26.4.2 Aponeurosis of the Shoulder

It is an extension of the superficial cervical fascia. Anteriorly it is formed by the fascia of the pectoralis major, laterally it forms the deltoid fascia, and posteriorly it bifurcates into a supraspinous and an infraspinous fascia. A fascia departing from the deep portion of the fascia of the pectoralis major courses towards the pectoralis minor, splitting into an anterior layer that reaches the pectoralis minor and attaches to the skin of the axilla, and a posterior layer projecting to the axillary pit. The two layers give rise to the suspensory ligament of the axilla, or Gerdy's ligament.

Two aponeuroses are found in the axilla (Paoletti 2003):

- superficial: from the lower border of the pectoralis major to the lower border of the latissimus dorsi
- deep: a square structure deep in the pectoral fascia extending towards the axillary border of the scapula as far as the humeral biceps anteriorly, the latissimus dorsi posteriorly, and the serratus anterior inferiorly (Fig. 26.3).

26.4.3 Fascia of the Arm

It continues the pectoral fascia and becomes the brachial fascia and the bicipital fascia; it extends to the elbow and inserts into the epicondyle, the medial epicondyle, and the olecranon. Here two cavities provide attachment to bone, offering an anchor point for muscle contraction. The lateral intermuscular septum divides the anterior from the posterior arm muscles and provides an insertion point for them too. The radial nerve and the deep humeral artery run through it.

The medial intermuscular septum fuses with the brachial tendon and reaches the medial epicondyle along the medial humeral aspect; one projection of the septum, the internal brachial ligament, reaches the lesser tubercle from behind the coracobrachialis muscle, separating the triceps from the anterior brachial muscle; from its deep portion depart sheaths

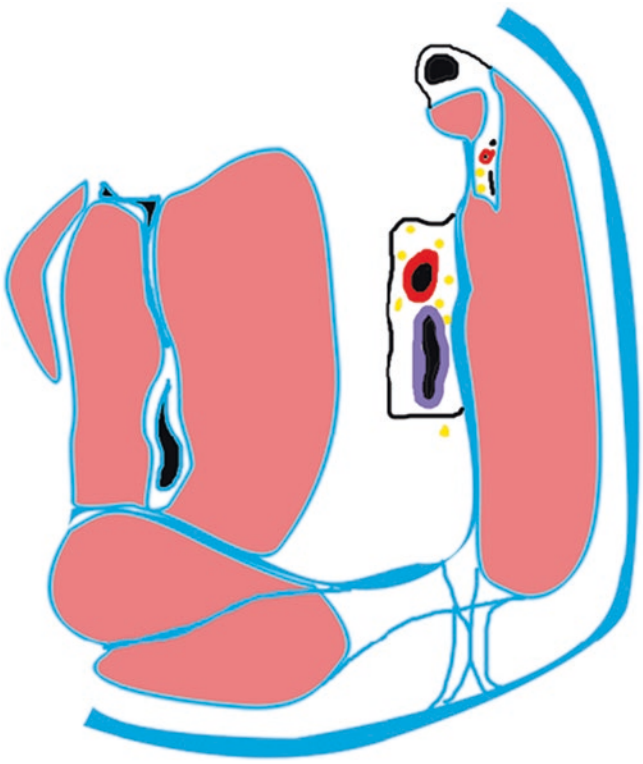


Fig. 26.3 Front view of the aponeurosis of the shoulder. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

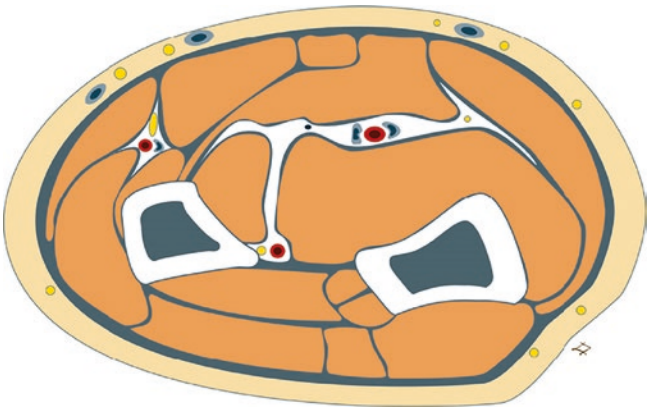


Fig. 26.4 Transverse view of the fascia of the arm. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

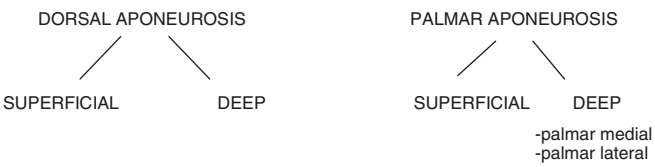
that envelop the triceps, brachial, coracobrachialis, and biceps muscles. In its inner portion, the humeral artery and vein and bands from the brachial plexus course through the brachial canal (Fig. 26.4).

26.4.4 Antebrachial Fascia

It is an extension of the brachial fascia. It reaches the carpus, where it is reinforced by the anterior and posterior annular ligaments. Sheaths departing from its deep portion provide for gliding of adjacent tendons. This aponeurosis divides the muscles into several groups.

26.4.5 Aponeurosis of the Hand

It continues from the antebrachial fascia and the anterior and posterior annular ligaments. It divides into:



In summary, the upper limb aponeuroses are extensions of the superficial cervical fascia and are in contact with the anterior and posterior thoracic fasciae. They are anchored at the level of the elbow and first and end at the level of the fingers. Interwoven vertical and horizontal fibres provide strength. Layers departing from the deep region insert into the periosteum, to enable gliding of muscles and muscle groups. They encompass the whole upper limb, and besides conferring functional unity they provide a route for trauma transmission between joints. This is why assessment of a condition affecting the elbow must include an evaluation of the shoulder and hand, and potentially also of the viscera, which are connected to the elbow through the thoracic fasciae.

26.4.6 Route of Injury Transmission

The hand is not a weight-bearing structure like the foot; accordingly, hand lesions are quite unlike foot injuries. The hand is involved in psychological and neurological aspects of personality; its functions include gesturing, social expression, and fine movement. Foot trauma is more frequent, whereas the hand is more elastic, reactive, and more "neurological"; its prompt reflex responses entail that, with the exception of direct trauma, hand and elbow problems like carpal tunnel syndrome or epicondylitis derive more often from the cervical spine through fascial or neurological transmission, from the scapulohumeral girdle, or from the clavicle. Therefore, whereas in the lower limb severe foot trauma is then transmitted to the iliac region (ascending chain), upper limb injuries follow the reverse route (descending chain). It is more common for a shoulder injury to reflect on the wrist than vice versa.

When dealing with the elbow, a comprehensive approach is particularly useful. The chain of injury transmission is clearly explained by osteopathic theories. At the end of the nineteenth century, Dr. Andrew Taylor Still, the founder of osteopathy, already discussed the functional unity of the body, the supreme role of the artery in the movement of body fluids through the body, and the fact that the function of all body parts depends on their structure. As regards the elbow, visceral tension due to nervous strain or psychological problems induces tension on the sternocostal triangle and through it on the clavicle and chest through spatial as well as functional connections.

26.4.7 Our Manual Rehabilitation Protocol

The effects of psichological stress on the patient include:

- faster heart rate;
- increased respiratory rate with shallow breathing;
- reduced sternoclavicular joint mobility;
- alteration of upper limb micro-movements;
- elbow or wrist pain. The lesion is transmitted throughout the fascial system. The fascia is neurologically sensitive to muscle changes and conditions, since it contains, separates, envelops, protects, supports, and even alters the structure. Assessment of elbow pain should thus prompt investigation of the wrist and, through the clavicle, the viscera.

Elbow trauma is often underestimated compared with shoulder and wrist injuries, which are considered more important and have been extensively investigated. In the clinic as in life, the value of a segment is best conveyed by its absence. An elbow blocked in 90° of flexion is severely disabling, since it does not allow the hand to reach the mouth or button up a shirt, nor does it allow to run in competitions, given the key contribution of the upper limbs to this activity (Fig. 26.5).

The inability to use a joint due to pain or pathology therefore gives rise to ascending and descending lesion chains. If while taking their history we ask patients with carpal tunnel syndrome whether they also experience ipsilateral shoulder or elbow pain, we will find that wrist or elbow pain is part of a chain of injury transmission that may begin at the cervical spine. It is therefore critical to investigate, by history as well as physical examination, not only the elbow but also the shoulder, wrist, cervical spine and scapula, bearing in mind their fascial interconnections. Epicondylitis is one of the clearest instances of these chains.

We feel that epicondylitis is often not a condition in itself, but the consequence of a lesion chain. To test this theory we conducted a study where patients were managed by osteopathic manipulative treatment. The approach was very effective. We hope that this information will prompt our colleagues in the various healthcare professions to adopt some of our suggestions and techniques and to recommend their patients to seek non-invasive therapies first, and to go on to more invasive approaches only if strictly necessary.

In the light of these considerations, our group devised a protocol based exclusively on osteopathic manipulative treatment (OMT) and on a single score for strength, range of movement (ROM), and pain, and tested it in a group of 26 patients. Outcomes were good without infiltration or physical therapy.

First of all, three main conditions enter into the differential diagnosis of epicondylitis (Rotini et al. 2000):

- plica synovialis of the elbow;
- tunnel syndrome (radial nerve);
- elbow joint conditions.

Although the diagnosis should be made by a physician, patients with lateral elbow pain are highly likely to refer to professionals who have closer relationships with their daily life, like a trainer, the gym instructor, or the rehabilitation therapist. This is why it is worth stressing that knowledge is the base for all professions, each with its competences and limitations.

26.5 Our Experience in Physiotherapy Treatment

In 2008/2009, we asked the patients diagnosed with epicondylitis who attended our rehabilitation centre in Forlì (Italy) about the outcomes of manual treatment, particularly OMT (see Chap. 40). The results of this survey enabled us to establish a practical approach to the condition and to draw up treatment guidelines. The first step is clearly diagnosis, which is based on the standard tests described in the literature, namely middle finger extension test (Fig. 26.6) and wrist extension with the elbow in extension, which elicit elbow pain (Hoppenfeld 1985; Mancini and Morlacchi 2003; Boccardi et al. 1991; Pellissier et al. n.d.; Cleland 2014) (Fig. 26.7); pain on epicondyle palpation (Smidt et al. 2002a, b; Stratford et al. 1989; Stratford et al. 1987) (Fig. 26.8); and the differential diagnosis process mentioned above.

Next, an ultrasound scan is obtained to document possible calcifications, the site of inflammation, and any tendon lesions. A personalized treatment plan is then drawn up based on diagnosis, the interval from pain onset, and ultra-

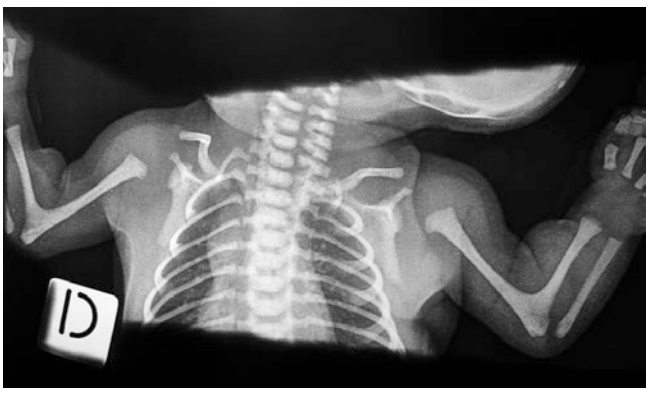


Fig. 26.5 X-ray scan of a neonate born without the elbow joints; there are no ossification centres between the ulna and humerus, which appear as a single bone. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.6 Middle finger extension test. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.7 Wrist extension with the elbow in extension. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.8 Epicondyle palpation. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

sound findings. The program involves a series of treatments that begin with non-invasive approaches and proceed with increasingly invasive therapies including infiltration of platelet-rich plasma (PRP).

On the first session with the patient, the physiotherapist's examination involves:

- assessment of active ROM including protraction and abduction to highlight any shoulder pain and stiffness (Figs. 26.9, 26.10, 26.11, and 26.12);
- investigation of scapular dyskinesis, which is often associated; active, resisted upper limb protraction, abduction, and external rotation highlight any scapular tilting or kinematic disturbances, which require specific exercises;
- elbow assessment in valgus and varus stress, medial and lateral Tinel's sign, passive ROM in all planes, chair sign, push-up test, and Mayo Elbow Performance Score (MEPS) (Celik 2014) (Figs. 26.13, 26.14, 26.15, 26.16, 26.17, 26.18, 26.19, 26.20, and 26.21);

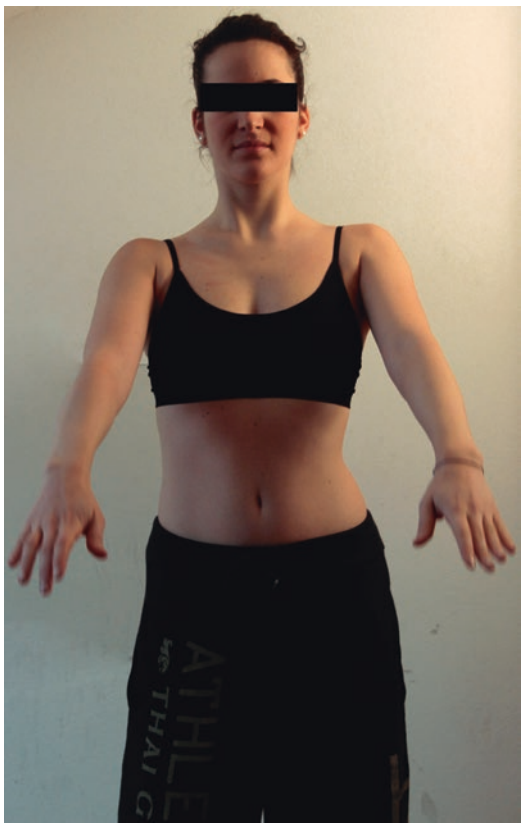


Fig. 26.9 Evaluation of active protraction. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

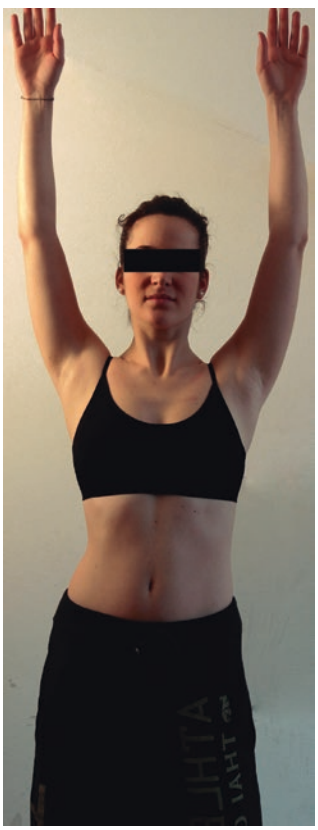


Fig. 26.10 Evaluation of active protraction. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.11 Evaluation of active abduction during the movement. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig.26.12 Evaluation of active abduction in different degrees. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

- craniosacral therapy (CST);
- evaluation and treatment of the dorsal spine, which is often involved in elbow pain, and of the Upper Thoracic Outlet (Fig. 26.22); fascial release of clavicles (Fig. 26.23); evaluation and treatment of the cervicodorsal junction (as needed), and treatment of the diaphragm to favour drainage (Fig. 26.24);
- forearm treatment with muscle massage (Loew et al. 2014), restoration of the balance of micro-movements of the humeroulnar and humeroradial joint (Figs. 26.25 and 26.26);
- treatment of the interosseous membrane of the forearm (Fig. 26.27);
- patient instruction for home-assisted scapular dyskinesis exercises (Fig. 26.28a, b);
- patient instruction regarding stretching exercises for the epicondylar muscles, to be performed at least 3–4 times a day (Cullinane et al. 2014; Hoogvliet et al. 2013a, b; Dimnjaković et al. 2012) (Fig. 26.29a, b).

Five to eight once weekly sessions of about 40 min are required, depending on the pace of improvement. If the pain diminishes, strengthening exercises can be added (eccentric contraction of epicondylar muscles (Cullinane et al. 2014; Dimnjaković et al. 2012)). These exercises are essential for overhead athletes and sport-practicing subjects in general, since they train muscle resistance to fatigue and prevent trauma when returning to the sport. We recommend compliant patients to use a thermoplastic counterforce brace to reduce epicondylar muscle tension, and to wear it as long as possible throughout the day (Dundar et al. 2015) during the treatment period (Fig. 26.30a, b).

The duration of sessions was at least 45 min; the first three sessions were once weekly, the fourth was held 15 days after the third, the fifth 20 days after the fourth, and the sixth was held 4 weeks after the fifth.

The osteopathic techniques that proved more effective in treating these patients, besides of course those for forearm and wrist soft tissues, were the shoulder joint techniques, particularly clavicular joint fascial release and acromioclavicular joint ligament counterstrain. We feel that in patients with chronic epicondylitis, work on the tissues and fasciae is critical to restore the equilibrium of the whole upper limb.

The results of treatment this group of 36 patients treated between 2008-2009 years, can be seen in the graphs shown below relating to mayo elbow performance score completed in the first session and after the last session of manual treatment (Fig. 26.21).

In the next step, if pain persists, PRP treatment can be performed.



Fig. 26.13 Varus stress. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.14 Valgus stress. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.15 Lateral tinel's sign. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.16 Medial Tinel's sign. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

26.5.1 PRP When?

In recent years blood products have found use in the treatment of chronic tendinopathy, exploiting the benefit of growth factors obtained from the separation of plasma from platelets procedures.

Growth factors are proteins capable of stimulating repair processes and tissue regeneration through biological mechanisms such as direct cell migration, proliferation, and cell differentiation. The circulating blood platelets contain a large amount of growth factors PDGF (platelet-derived growth factor) and Transforming Growth Factor Beta (TGFß), both have been found in the alpha granules of platelets.

The growth factors can be extracted from the venous blood and concentrated to obtain a preparation known as "platelet rich plasma" (PRP). The concentration of growth



Fig. 26.17 Chair sign . Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.19 Push up sign. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.18 Chair sign. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.20 Push up sign. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

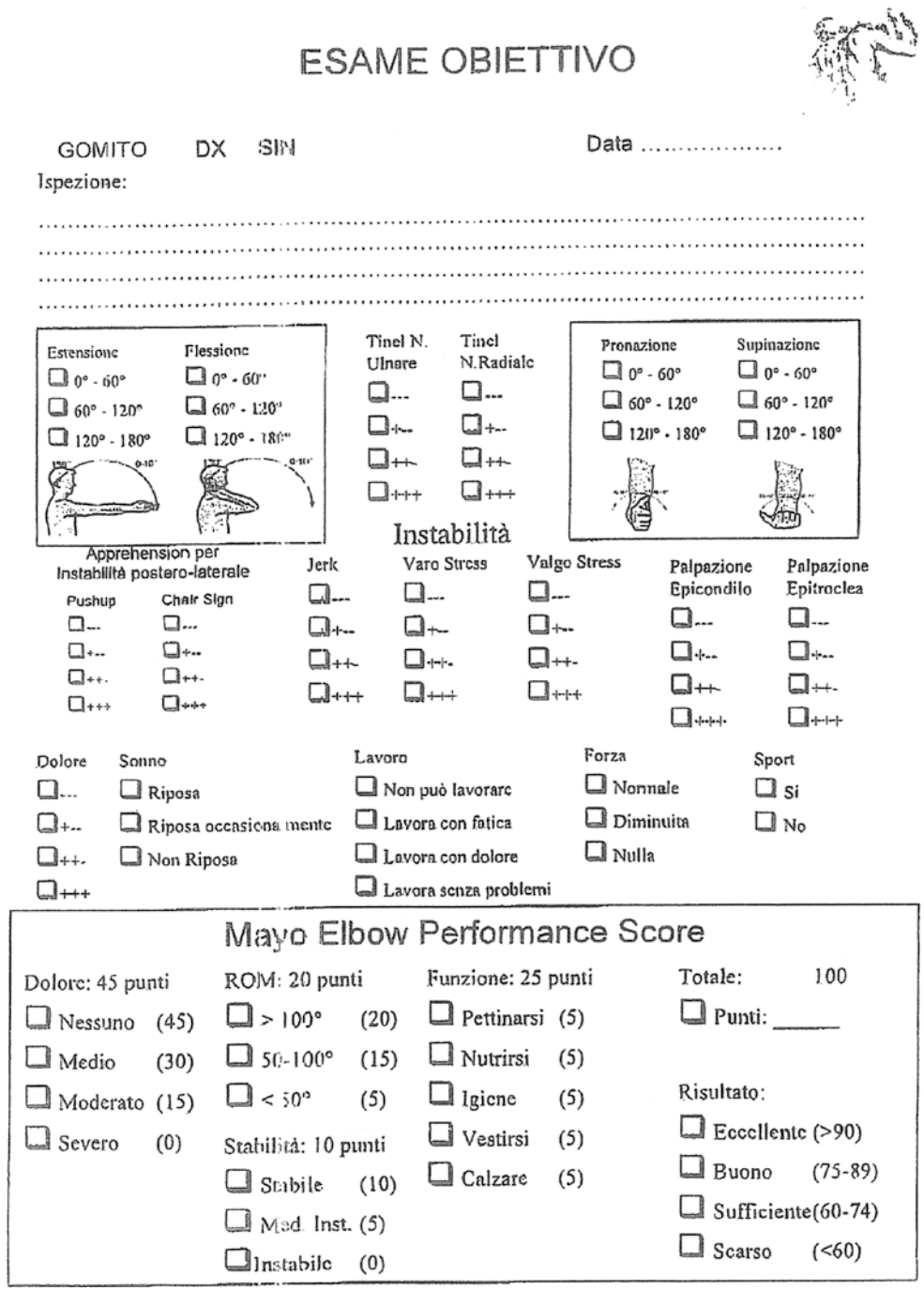


Fig. 26.21 Mayo elbow performance score and evaluation scale. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

Fig. 26.21 (continued)



Graphic of the mean trend of the values investigated before and after the manual treatments



Fig. 26.22 Evaluation of upper thoracic outlet

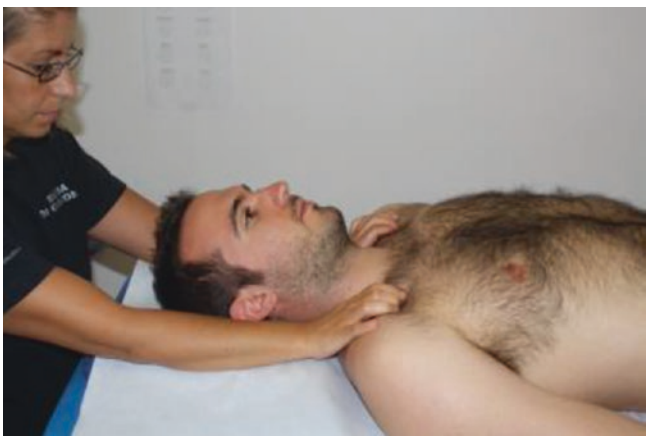


Fig. 26.23 Realease of clavicles technique. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.24 Treatment of the diaphragm



Fig. 26.26 Posterior radial head technique. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.25 Balance of micro-movements of the humeroulnar and humeroradial joint. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

Fig. 26.27 Treatment of the interosseous membrane of the forearm



factors contained in PRP activates some biological functions by promoting regeneration and repair of bone and soft tissue in the atria treated areas, with powerful anti-inflammatory effect. Recent studies have shown that PRP administered locally activates and accelerates the repair processes of the connective tissue, such as tendon injuries, muscle, meniscal, chondral, and osteochondral. Epicondylitis treatment with PRP aims to reduce or eliminate pain, inflammatory events, to recover the functional limitation, reduce or eliminate more aggressive therapies or side effects the intended route for the preparation of the PRP at our U.O provides.

The pieces considered appropriate, on the basis of blood tests performed at home, will be sent to U.O Immunohaematology and Transfusion Medicine Hospital "Sick" of Rimini to undergo self-giving.

The donated blood is subjected to careful preparation, following product standards as required by regulations, by storing the rates that are subject to manipulation "home made" made in a clean room (class D) and repeated quality control and sterility, then stored 8–10 in mini-bags and finally cryopreserved −80 °C for 12 months.

Infiltrative treatment with the preparation containing autologous PRP described above is performed using the prepared transported by ambulance from U.O Immunohaematology and Transfusion Medicine Hospital of Sick Rimini to U.O of Surgery of Hospital Shoulder Cervesi Cattolica. After a correct identification of the patient and his

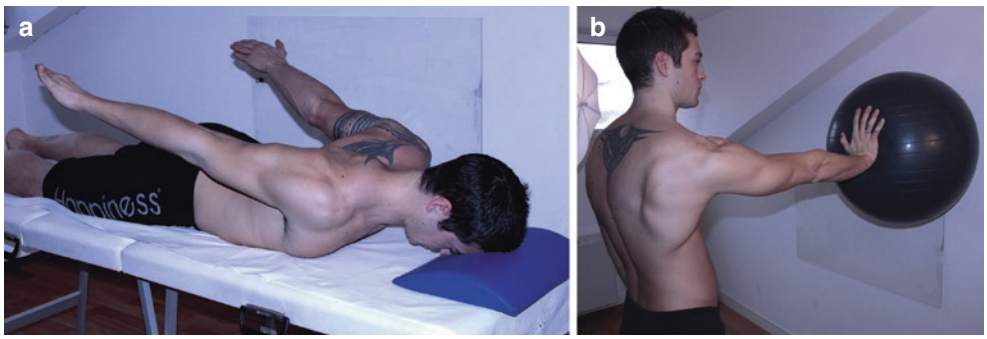


Fig. 26.28 (**a**, **b**) Home-assisted scapular dyskinesis exercises. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

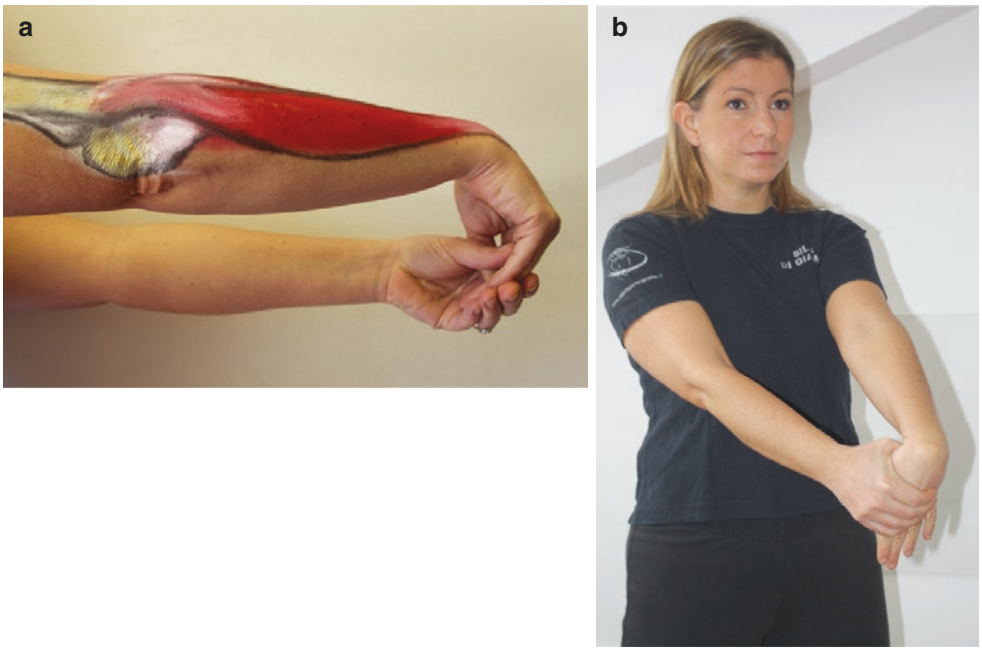


Fig. 26.29 (**a**, **b**) Stretching of epicondylar muscle. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

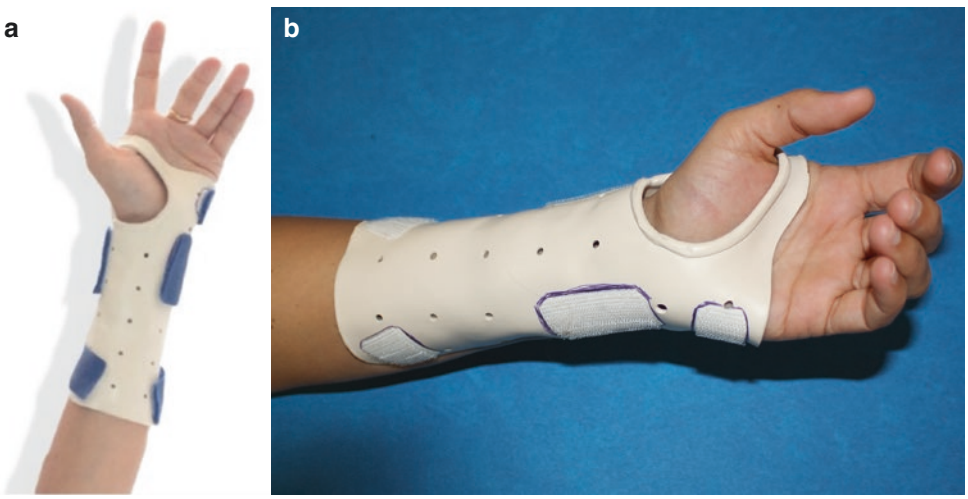


Fig. 26.30 (**a**, **b**) Customized counterforce brace with wrist extension to reduce epicondylar muscle tension

blood product, it will proceed to the sterile field preparation and injection at the site epicondiloidea epitrochlear interested or 3 cc of autologous PRP and calcium gluconate 1 cc. The affected area is covered with a pressure dressing. The treatment involves three infiltrations carried out at a distance of 15 days each other.

All patients are evaluated with visual analogue scale for pain (range 0–10) and the Italian version of the subjective system PRTEE scores (Patient-rated Tennis Elbow Evaluation) which is composed of two sections (pain and disability) by the sum of which you get a score between 0 (worst score) to 100 (best score). The follow up controls will be performed at T0, 3–6 months and 12 months.

Before surgery, that is therefore the last resort after an appropriate patient-tailored rehabilitation treatment (Sims et al. 2014), we can involve exploration of the feasibility of shock wave therapy based on pain and lesion type, and especially on the presence of calcifications that are amenable to this approach, like described in shock wave paragraph.

26.5.2 Shockwave Treatment: When?

Elbow enthesopathies are included in the Recommendations for ESWT (Extracorporeal Shock Wave Treatment) both of SITOD (Società Italiana Terapia Onde D'urto, www.sitod.it) and ISMST (International Society for Medical Shockwave Treatment, www.shockwavetherapy.org), among "approved standard" (epicondilytis) and "common empirically-tested" indications (epitrochleitis), respectively.

Among "soft tissues" diseases, suitable for SW (Shock Waves) application, elbow enthesopathies surely play a major role, together with some other tendinopathies and regardless of calcifications (d'Agostino et al. 2015; Notarnicola and Moretti 2012). As described in the specific SW chapter, the final action of SW stimulation on living tissues is not the pure mechanical effect, but rather the biological consequences: SW are applied not for a "destructive" purpose. From this point of view, possible disappearing of calcification can be related to its dissolution (biological action), rather than to the disruption or fragmentation of calcific deposits, and calcifications do not affect the final effect of the therapy (d'Agostino et al. 2015; Notarnicola and Moretti 2012).

According to the recent new ISMST Consensus Statement (Naples, 2016) very few absolute contraindications should be respected: malignant tumour in the site of treatment, foetus in the treatment area, and heamophilia, and some other conditions, as for example anticoagulant therapies, growth plates, etc. must be evaluated case by case, according to the specific SW protocol requested, device to be utilized, and experience of the operator (Sistermann and Katthagen 1998).

The first scientific works regarding ESWT application in elbow enthesopathies date from the mid-nineties, already in 1996 Rompe et al. wrote: " …ambulatory shock wave therapy is a considerable alternative before surgical intervention in chronic tennis elbow …" (Rompe et al. 1996). About one year later, he confirmed that " … prospective studies demonstrated beneficial effects in chronic lateral humeral epicondylitis (tennis elbow), … in more than 50% of the cases… and, on the basis of the results achieved, for specific indications, ESWT may now be taken out of the clinical testing stage and introduced into routine practice …" (Rompe et al. 1997). Nevertheless, the scientific history of SW application in elbow (and other anatomical districts) tendinopathies and enthesopathies is characterized by a long series of conflicting results, in spite of a growing body of basic science data, describing the positive biological effects of SW on tendons and tenocytes. The first ISMST recommendations for SW treatments, written in the Consensus Statement, were put together without applying Cochrane standards levels of evidence. Already at that time (year 2008), in fact, by analysing many studies, it could be shown that inclusion criteria, treatment parameters, and other conditions were afflicted with systemic biases, which turned the results of the studies completely into opposite. The ISMST Board concluded therefore that "as long as the situation was so incoherent, the idea of a ranking due to the level of evidence was not reasonable or feasible" (www.shockwavetherapy.org).

This discrepancy continued in the following years, especially if we consider that, more recently, in spite of many scientific studies that demonstrate the therapeutical effects of SW in epicondilopathy (mainly "tennis elbow"), some other ones seem to still express some controversial or negative results, especially for the medial form of elbow enthesopathy (Ciccotti et al. 2004; Lee et al. 2012; Krischek et al. 1998; Krischek et al. 1999). The multiple variables associated with this therapy, such as the type of SW source, amount of energy delivered, method of SW focusing, frequency and timing of delivery, type of treatment and control group, timing of follow-up, clinical evaluation scales and whether or not anaesthetics are used, make comparing clinical trials difficult and seem to confirm them as a cause of the overcoming therapeutic nihilism against SW, with respect to the non-operative management of this condition (Maier et al. 2001; Rompe and Maffulli 2007). On the other hand, well-designed randomized control trials have provided evidence of the effectiveness of SW intervention for tennis elbow (Rompe et al. 2005). Finally, very recently, Thiele et al., while recognizing that SW treatment of lateral epicondylitis shows conflicting results, if doing an overview of the published RCTs, nevertheless concluded that it can be still considered a main indication for ESWT and pointed out how methodological failures can negatively affect to demonstrate ESWT efficacy in elbow tendinopathies (Thiele et al. 2015).

Nowadays, in clinical practice, SW applied in elbow (and other) tendinopathies are chosen when all other conservative

therapies have failed, when it is reasonable that common therapies will not exert any rapid or successful effect (chronic diseases), as a "last resource" before prescribing some invasive procedure (from infiltrations to surgeries), and even after surgery or some other invasive procedures, characterized by persisting pain and related syndromes, also considering that several valid and incontrovertible scientific evidences seem to suggest a possible direct action of SW on tendon structures and cells (d'Agostino et al. 2015; Visco et al. 2014), thus further indirectly confirming that "efficacy" seems to be not a biological problem, but rather a methodological one (d'Agostino et al. 2015; Rompe and Maffulli 2007). Based on the results of their preliminary study, for example, some of the authors in the literature recommended also radial shock wave therapy (rSWT) in the treatment of lateral epicondylitis of more than 6 months duration, if the condition is recalcitrant to other conservative methods of treatment (Ilieva et al. 2012). The use of rSWT has been proved in fact to reduce pain, and functional impairment, together with an increase of the pain-free grip strength test, in patients with tennis elbow (Spacca et al. 2005; Haupt et al. 2006).

From a general point of view, the SW success rate reported in the literature for epicondylitis ranges from 60% to 91% (as much as in plantar fasciitis, cuff tendinitis, trocanteritis, Achilles tendinitis or jumper's knee), only 27% for the epicondylitis humeri ulnaris (Notarnicola and Moretti 2012; Wang 2012). Moreover, the comparison of some alternative therapeutical procedures with ESWT seems to underline the efficacy of this mechanical stimulation (Lee et al. 2012; Ozturan et al. 2010; Radwan et al. 2008) that can be considered also a useful treatment option in patients for whom local steroid injection is difficult (Lee et al. 2012).

Independently of the type of device we can use, if properly applied, after learning and training, from a general point of view, low-dose shock wave therapy without anesthetic can be considered a safe and effective treatment for chronic lateral epicondylitis (Pettrone and McCall 2005a, b; Furia 2005). No device-related problems, systemic, or local complications are reported; ESWT may represent a new and safer non-operative treatment for patients with lateral epicondylitis of the elbow (Ko et al. 2001).

From a general point of view, some SW definite advantages can be summarized as follows:

- it is a safe, non-invasive, rapid, well tolerated (if correctly applied), and repeatable medical procedure;
- it can be associated with all other therapies (both medical, infiltrative or surgical one) in different phases, on "outpatients";
- it is a relatively "low cost" therapy, in comparison with some other bio-surgical procedures;
- it offers the possibility to treat not only «tendons» but also all other sources of pain (like muscles, bone, and fascia);
- it can be applied also as post-surgical therapy, if persistent pain or some other related disturbances occur.

Nevertheless, for ensuring maximum effectiveness of the therapy, it is essential that certain requirements are met:

1. correct diagnosis and experienced operator (preferably certified);
2. precise targeting of the affected structure/s;
3. regular monitoring of clinical changes and customization of ESWT protocol, according to the patient's general conditions/comorbidities and response to SW application.

Already in 1997, Haupt wrote " … in patients in whom conservative treatment has failed, surgery used to be the only choice, but its success rate barely exceeds that of shock wave therapy and surgery can still be done if shock wave therapy fails. Extracorporeal shock waves will have an impact on orthopedics comparable to its effect in urology. Scientific evaluations, professional certifications, quality assurance and reimbursement issues present great challenges …" (Haupt 1997).

It is impossible, nowadays, not to remember the words of Haupt, pronounced in a little bit "pioneeristic" discipline, that became a clinical reality, due to the efforts of many researchers and clinicians, over the last twenty years. Finally, already surpassed the "pioneeristic" phase, ESWT reveals itself as a versatile therapeutic tool for the treatment of elbow tendinopathies: it can be applied both in standard indications and as adjuvant resource, together with other surgical and non-surgical therapies as well. In the near future, some further clinical and experimental studies are expected, in order to increase scientific evidences, to maximize the benefits and enhance SW therapeutical dignity in the field of Regenerative and Rehabilitative Orthopaedic Medicine.

26.5.3 Rehabilitation After Surgical Approach

Rehabilitation after surgical management involves several stages that are based on the principles of the chain of dysfunction and injury transmission. They can be summarized as follows:

1. passive mobilization from the third postoperative day to avoid stiffness, which would compound the existing condition (Figs. 26.31 and 26.32);
2. in case of intense pain, upper thoracic outlet drainage may help; working the wrist and forearm may also help, treating the patient rather than the condition;
3. treatment of surgical scars;
4. from the 35th postoperative day, rehabilitation in a pool with gentle, progressive mobilization of the whole arm (if passive ROM has been recovered, sessions can be halved to twice monthly)



Fig. 26.31 Passive mobilitation to avoid elbow stiffness in flexion. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.32 Passive mobilitation to avoid elbow stiffness in extension. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.33 Starting position for eccentric contraction exercise for epicondylar muscles. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 26.34 Arriving position in eccentric contraction exercise for epicondylar muscle, in this exercise the patient returns to the starting position without tube resistance. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

5. from the 50th day, slow, progressive strengthening of epicondylar muscles by eccentric contraction exercises (Figs. 26.33 and 26.34);
6. from the 60th day, adoption of a work program envisaging progressively more demanding work against elastic tubing for the shoulder as well as the elbow instead of the exercises in the rehabilitation pool, in agreement with the surgeon;
7. in the case of athletes, recovery of the athletic gesture also through stimulation of mirror neurons, i.e. observation of the gesture executed by other athletes;
8. at 90 days, return to competitions after isometric assessment of upper limb strength and verification that the strength deficit does not exceed 10% compared with the contralateral arm (see Chap. 32).

26.6 Epitrochleitis (Medial Epicondylitis)

Epitrochleitis (golfer's elbow) is less frequent than epicondylitis, but over the past few years it has gradually become more common among high-level athletes, both golf and tennis players as well as subjects who work on a computer many hours a day (Demartin and Schiavi 1970). The literature on its physiotherapeutic treatment is very limited. In 2013, Waissman and colleagues published a



Fig. 26.35 Strengthening exercises of the humeral head depressors with elastic resistance at the level of the elbow. Front side. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

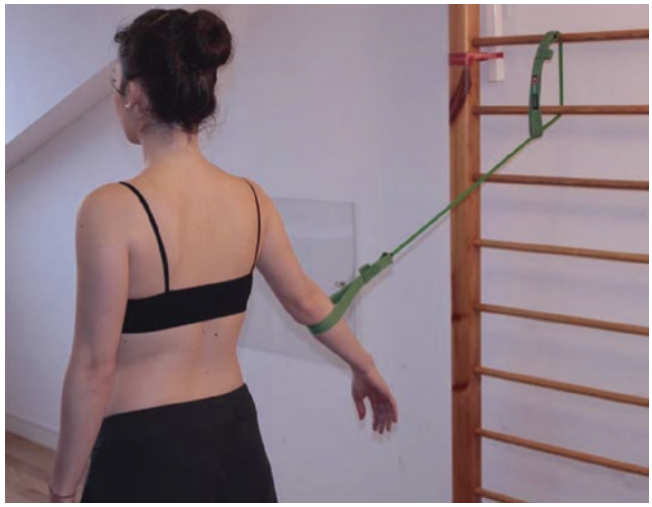


Fig. 26.36 Strengthening exercises of the humeral head depressors with elastic resistance at the level of the elbow. Lateral side. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torinof

study where they tested the value of body awareness to address writer's cramp, associated with a splint to manage muscle dystonia (Waissman et al. 2013). The tennis elbow has always been called for epicondylites but, in recent year, tennis player also suffer epitrocleitis as golf player, for typical gear and gestures used in these sport. We feel that medial epicondylitis should first be managed with the less invasive treatments, based on a holistic view of the patient. The first step of the rehabilitation of medial epicondylitis will thus involve:

- assessment of the whole upper limb, testing the macro-movements of the shoulder to enable strengthening of this compartment; patients (both those with epicondylitis and epitrochleitis) should avoid grasping the elastic tubing, since it could elicit elbow pain; Figs. 26.35 and 26.36;
- treatment of the soft tissues of elbow and clavicle, upper thoracic outlet, diaphragm (especially the hepatic cavity in case of right medial epicondylitis), and scapula;
- release of the interosseous membrane;
- deep transverse friction massage of medial epicondylar muscles
- stretching of epitrocleytis muscles (Fig. 26.37)

In case of a patient managed by surgery the guidelines are as follows:

- 0–15 days of immobilization in an orthosis, with passive wrist, scapula, and shoulder mobilization; during this time the therapist, without forcing and based on the type of operation, will work to prevent the onset of elbow stiffness;
- 15th–35th day, passive mobilization in all planes;



Fig. 26.37 Stretching of epitrocleytis muscles. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

- from the 35th day, rehabilitation in a pool; sessions in the office will be suspended only if the patient has achieved a satisfactory passive ROM and does not risk stiffness onset;
- from the 60th day, progressive strength recovery exercises with elastic resistance; during pool rehabilitation the elbow will have been trained for strength and resistance,

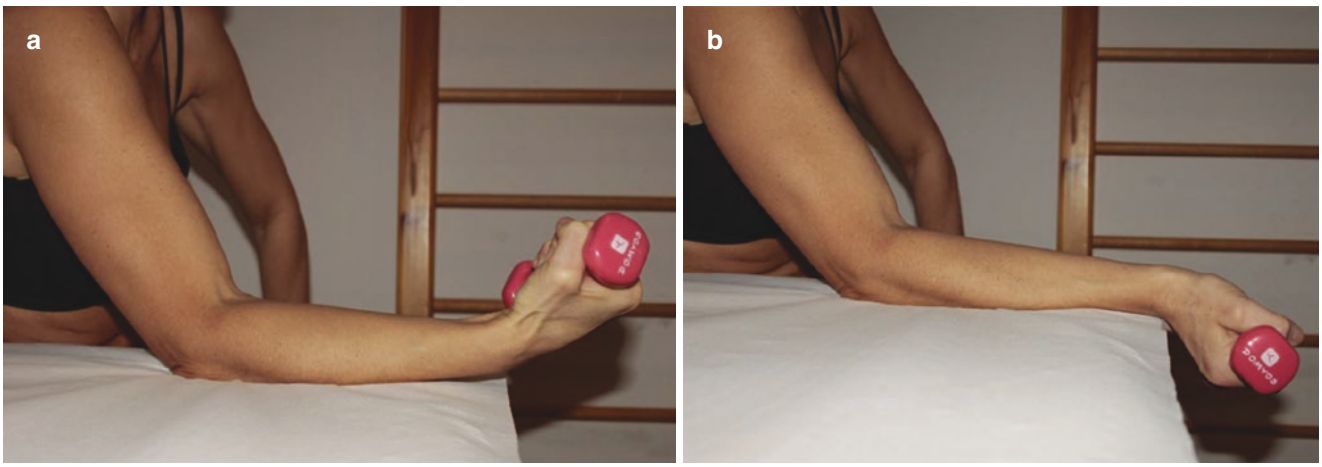


Fig. 26.38 Progressive strength recovery exercises in eccentric contraction start from (**a**) and arrive in (**b**). The return must be done without weights. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

now the same exercises will be performed out of the water (Fig. 26.38);
- from the 90th day, training of the athletic gesture; in non-athletes, specific exercises aimed at daily activities.

A surgeon who treats a patient with epicondylitis or epitrochleitis with cortisone infiltration as the first-line treatment, to avoid surgery, will nonetheless make eventual surgery necessary. As the patient requires more cortisone infiltrations surgery will become inevitable, because manual treatment is more effective if it acts on a tendon that has not undergone physical therapy or infiltration, which alters its matrix and accelerates the tendinosis and the fibre thickening process.

Rehabilitation highlights

1ST MANUAL TREATMENT AND OSTEOPATIC TREATMENT:

evaluation of shoulder elbow and wrist

8 session of manual therapy and osteopathic treatment

global treatment, stretching and strength exercises every day for a month

2nd PRP

3 infiltrations at a distance of 15 days each other

3rd SHOCKWAVE THERAPY

3/4 sessions at a distance of 1 week each other

4th SURGERY

artroscopic or open technique

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Distal Biceps Brachii Injury

27

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27.1 Anatomy

The biceps is inserted distally on the bicipital tuberosity of the radius, defining its role as supinator of the forearm and elbow flexor. The tendon fibers shall commence in the coronal plane rotating clockwise in the sinister elbows and counterclockwise in the right elbow (Kulshreshtha et al. 2007; McDonald et al. 2013).

In addition, the anterior-medial fibers follow a straight path until their insertion, while posterior-lateral fibers rotate under the medial fibers up to the top of the tuberosity.

The long head of the biceps fits more proximally than the short head and medially from the central axis of the forearm; it acts primarily as a supinator of the forearm, while the short head fits more distally, acting mainly as a flexor of the elbow. The bicipital tuberosity has a length of about 22 mm and a width of 15 mm, while the tendon insertion has a length of 22 mm and a width of 7 mm. From the medial margin tendon insertion, where it moves toward the elbow joint, a foil, the "fibrous fragment" originates and expands downward, medially merging with the antebrachial fascia, which results in the identification of a landmark that allows for the correct orientation of the reconnection of distal biceps tuberosity.

The biceps is innervated by the musculocutaneous nerve which, 61% of the time, consists of a single branch (Pacha Vicente et al. 2005) and is vascularized by bicipital branches of the brachial artery.

The rupture of the distal biceps is relatively rare, but it can bring significant functional consequences.

In 1938, Gilcreest reported that 96% of the lesions of the brachial biceps are localized to the long head, 3% to the distal insertion, and 1% to the short head (Gilcreest 1936; Spang et al. 2006; D'Alessandro et al. 1993).

27.2 Epidemiology

Injuries of the distal biceps occur most frequently in the dominant limb and are more likely to affect sportingly active male subjects between the ages of 30 and 70 years old, especially young athletes who practice contact sports, strength exercises, and weight lifting (Arianjam et al. 2013).

Safran and Graham conducted a retrospective study involving 14 patients treated over the course of 5 years, for the purpose of identifying the demographic characteristics and the effect of smoking on the incidence of rupture (Safran and Graham 2002). The reported incidence was 1.24 breaks per 100,000 patients/year, with an average age at the time of the trauma of 47 years. The dominant side was involved in 86% of cases, and smokers had a 7.5 times higher risk of such ruptures than non-smokers. In fact, the vasoconstrictor and deoxygenating effect of the nicotine is involved in the degeneration of the distal biceps tendon in other studies (Schneider et al. 2009; Seiler et al. 1995; Strauch 1999). The use of anabolic steroids has been associated with an increased risk of breakage. The use of anabolic steroids has also been associated with an increased risk of fractures, most likely due to the induction of dysplasia of collagen and, consequently, to a lower resistance of the tendon to tension (Schneider et al. 2009; Seiler et al. 1995; Strauch 1999; Visuri and Lindholm 1994), as well as local infiltration with corticosteroids, all of which have been identified as predisposing factors (Ford and DeBender 1979).

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27.3 Etiopathogenesis

The pathogenesis of distal biceps ruptures has not yet been fully determined. The most frequent lesion mechanism is an eccentric unexpected load on biceps when the elbow is slightly flexed, which involves the complete avulsion of the insertion of the distal biceps from tuberosity of the radius (Johnson et al. 2008).

The most recent theories affirm that tendon degeneration is caused by both mechanical and hypovascular factors. Seiler has performed an anatomical and radiographic study to clarify these mechanisms and noted a hypovascularized area of 2.14 cm of diameter in correspondence with areas of focal degeneration; this defect of vascularization could predispose the tendon to rupture (Seiler et al. 1995). In the same study, CT of the elbow in maximum supination, neutral position, and maximum pronation was performed. The distance between the lateral border of the ulna and the bicipital tuberosity of the radius, which corresponds to the space available for the tendon, is reduced by 48% with the forearm at maximum pronation compared to maximum supination. Also at maximum pronation, the tendon occupied 85% of the available space at the radioulnar level, which leads them to believe that a mechanism of impingement could also be a predisposing factor for tendon rupture.

27.4 Diagnostic Evaluation

Tears of the distal biceps tendon are classified either as partial and complete or acute (up to 3 weeks after the event) and chronic (Kelly et al. 2000). The patient reports a sensation of painful "snap" at the moment of the trauma and describes a sudden pulling sensation in the antecubital pit followed by a dull ache. The characteristic symptoms are pain and reduced strength in elbow flexion (20%) and in supination (40%) compared to the contralateral (Morrey et al. 1985). In addition, patients present swelling and bruising.

At palpation, the rupture appears as a palpable defect in the cubital fossa and often is evident in the retraction of the muscle belly more proximal in the arm if the lacertus fibrosus is also completely interrupted.

A complete rupture shows a retraction of the muscle belly and an abnormal profile of the biceps. A rupture can be misunderstood, however, in case of a fibrous fragment that may remain intact.

A differential diagnosis should be considered in relation to other causes of pain in the front of the elbow, such as cubital bursitis, biceps tendinitis, or lateral antebrachial cutaneous nerve syndrome.

Some studies have tried to facilitate the diagnosis of rupture of the distal biceps head. Ruland proposed the squeezing test, similar to the Thompson's test used for the diagnosis of rupture of the Achilles tendon (Ruland et al. 2005). The biceps is squeezed getting a supination if the tendon is intact. The diagnosis of rupture was confirmed by surgery or MRI in 23 out of 24 patients with positive test results; also the squeezing test was negative in 21 patients with complete rupture who underwent surgical reconnection. The hook test described by O'Driscoll et al. (2007) showed 100% specificity and sensitivity, while the MRI showed 92% of sensibility and 85% specificity in the same cohort of patients. While the patient actively flexes the elbow at 90° with the forearm kept at maximum supination, the examiner uses a finger as a hook by pressing it against the lateral margin of the biceps tendon between the biceps tendon itself and the brachial muscle. If the tendon is intact, the examiner can fully insert a finger 1 cm below the tendon (Miyamoto et al. 2010).

It is important to perform the hook test on the lateral margin of the tendon, as the fibrous fragment can be confused with the medial margin of the intact tendon. Attention should be drawn to the fact that the hook test can be negative in cases of partial tears because the fragment can simulate an intact fibrous tendon. Another test is performed by keeping the elbow at 90° of flexion, supinating and pronating the forearm alternately. The biceps should be checked during movement; if the tendon is intact, the muscle moves proximally in supination and distally during pronation. If the tendon is broken, the muscle belly does not move during pronation and supination (Harding 2005).

An X-ray examination can exclude an avulsion of the biceps tuberosity of the radius. Advanced diagnostic imaging such as MRI can be a slight problem in the case of partial tears, but the diagnosis of rupture of the distal biceps is essentially clinical. MRI may be useful in the evaluation of tendon retraction in case of chronic ruptures.

In their 2005 study, Chew and Giuffrè (2005); Ford and DeBender 1979 recommend performing an MRI with the patient in FABS position (FABS, elbow flexion, shoulder abduction, and forearm supination) which puts the tendon under tension and decreases the rotation, showing the tendon with longitudinal course in the MRI.

The patient lies prone on the bed, with the elbow flexed at 90°, arm abducted, and forearm supinated so that the thumb points upward. The MRI performed in FABS position shows the tendon insertion in closer detail and simplifies the differential diagnosis of partial and complete lesions.

Alternatively, an ultrasound exam can be used to confirm the diagnosis, which allows for dynamic images and to compare the tendon with the contralateral (Belli et al. 2001; Giuffrè and Lisle 2005; Gilcreest 1936; Johnson et al. 2008).

Although it is operator dependent (Balabaud et al. 2004), the ultrasound has been shown to be a valid and low-cost diagnostic tool.

27.5 Treatment

27.5.1 Surgical Treatment

The first surgical techniques involved the anterior access (or Henry's approach) with a single curvilinear incision centered on the antecubital fossa (McKee et al. 2005); this access posed the risk of injury of the radial nerve or posterior interosseous nerve (Dürr et al. 2000; Sutton et al. 2010; An et al. 1981). To avoid this risk, Boyd Anderson developed a technique that included a double incision and an interosseous access to reinsert the biceps to the radius through a bone tunnel (An et al. 1981). Kelly further modified the second access with a posterior approach through the muscle, dissociating the fibers of the extensor carpi ulnaris (Idler et al. 2006). The preparation of the radius, however, entailed the risk of postoperative calcification and radioulnar synostosis (Gasparella et al. 2014).

A fixation technique was proposed later on, with anchors that used again a single front access in space bounded by the brachioradialis and pronator teres with technical difficulties and the risk of nerve damage (Mazzocca et al. 2007). Then, a technique was described that involves a cortical fixation with Endobutton (Kelly et al. 2000). However, a preparation of radius with a risk of calcification and synostosis is required. Related literature suggests that the techniques with a single anterior incision are associated with risk of nerve damage, while dual access or techniques that require more preparation of the radius lead to a greater risk of calcification and synostosis. The anterior approach is now performed even with a small transverse median incision that seems to reduce the risk of nerve damage (Dobbie 1941).

27.5.1.1 Fixation Techniques

The current fixation techniques essentially provide four different methods:

- Intramedullary fixation with transosseous suture
- Tenodesis with interference screw
- Suture anchors
- Intramedullary fixation with cortical button

The simple elbow flexion to 90° exerts a force of 90 N (Baker and Bierwagen 1985) on the tendon. The tendon rupture is produced by applying a force of 204 N (Morrey et al. 1985). Current techniques are designed to allow early mobility. In the double-incision techniques, a slot is created in the radial tuberosity, and a bone bridge for the sutures using the posterior access is performed (Dobbie 1941). Suture anchors or tenodesis screw fixation can be performed using a single anterior approach and keeping the forearm in supination: the tendon is reinserted with one or two anchors or with an interosseous screw after preparing the tuberosity. Perforation of the posterior cortex is therefore avoided. Gasparella reported good results on 14 patients at a mean follow-up of 26 months using a fixation with two anchors. A deficit of supination (Chillemi et al. 2007) was found in two cases. Transosseous fixation techniques with a cortical suspensory button were also developed. These techniques provide a preparation of the radial tuberosity and the creation of a slot for the biceps tendon with a 4 mm hole (Dobbie 1941). A radiological control of the correct positioning of the button is mandatory. The suture fixation with cortical turned out to be the most tolerant to the load: the fixation with Endobutton has a breaking load of 270 N, while still TWINFIX QuickT does not resist more than 57 N. Mazzocca studied the cyclic load breaking, highlighting that the technique with Endobutton presents a significantly higher load than other techniques: 440 N against 381 N of the anchors, 310 N of the bone tunnel, and 232 N of the interference screws (Freeman et al. 2009). Mazzocca also studied the cyclic mobilization of the different fixation techniques with inverse results: the interference screw with the smallest mobilization. These movements may delay or inhibit the healing process. In order to improve the fixation, other techniques have also been proposed that associate an interference screw fixation with the button. In these cases, a bone tunnel of 8 mm is necessary (Dobbie 1941). None of these techniques are free from risk of complications related to accesses and to a more invasive radial preparation.

27.5.1.2 Intramedullary Repair with Cortical Button

The patient is in supine position with the arm lying on a table with the tourniquet at the root of the arm. We use an anterior approach with an oblique or longitudinal incision of approximately 6–8 cm in the middle of the forearm, about 2 cm distal to the elbow crease (Fig. 27.1). This procedure is performed by blunt dissection under the skin, in order to avoid injury to the lateral cutaneous nerve of the forearm which is retracted laterally to be protected. We proceed by separating the interval between the pronator teres muscle and brachioradialis, where it is common to see veins of large diameter that flow into the basilic and cephalic veins. In addition to these vessels, the radial artery is often present, which can be tied, if necessary. If the tendon is retracted, it can be gently mobilized to rescue from adhesions formed after the trauma. Once freed, the injured tendon is basted. The degenerated distal portion is cut to about 0.5 cm. In our practice, the tendon is prepared with n. 2 wires with Bunnell sutures followed by a suture of Krakow for 3 cm. The distal centimeter of the tendon is not basted, but it is left as a shortening zone with the sutures passing inside in a straight line ("sliding zones"). This will allow the tendon to shorten up and to lay the button easily on the cortex, which is secured

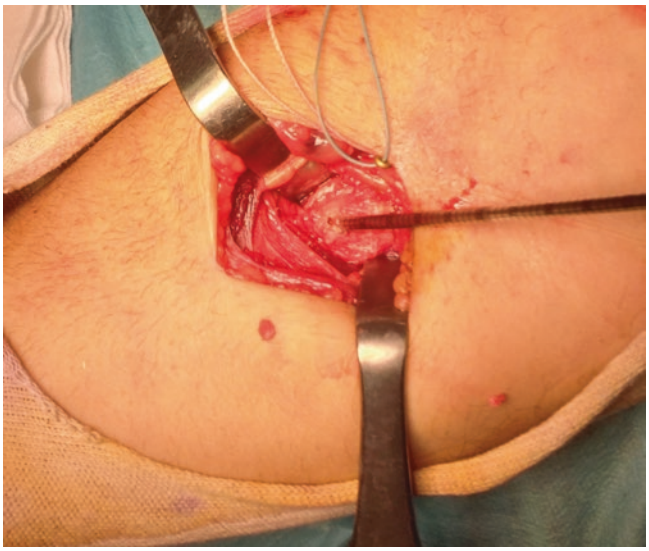


Fig. 27.1 The guide wire, which measures 1.5 mm, is inserted in the proximal half of the radial tuberosity in a medial-lateral direction to avoid lesions to the posterior interosseous nerve

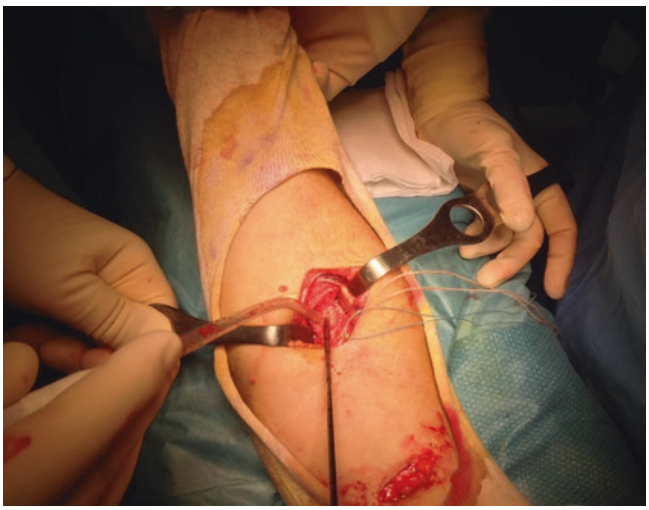


Fig. 27.2 The first milling cutter used measures 4 mm with an angle of nearly 45° compared with the level formed from the radial tuberosity to avoid genuflexion of the tendon during extension of the forearm

with both sutures at about 2–3 mm from the tendon. Once the tendon is basted, the biceps bursa is opened leading to the radial tuberosity. Serous fluid and hematoma often come out of the sheath. This helps to easily identify the radial tuberosity. Once the tuberosity is skeletonized, the forearm of the patient is supinated; we insert a slotted 1.5 mm wire, at a 45° angle compared to the level of the tuberosity, which will serve as a guide for the cannulated cutter of 4 mm (Fig. 27.2). It serves as a first bicortical tunnel of about 4 mm (depending on the device used). Using the slotted wire as a guide, with a 7–9 mm cutter, according to the measures of the diameter of the tendon, a half tunnel of approximately 1.5 cm in length is

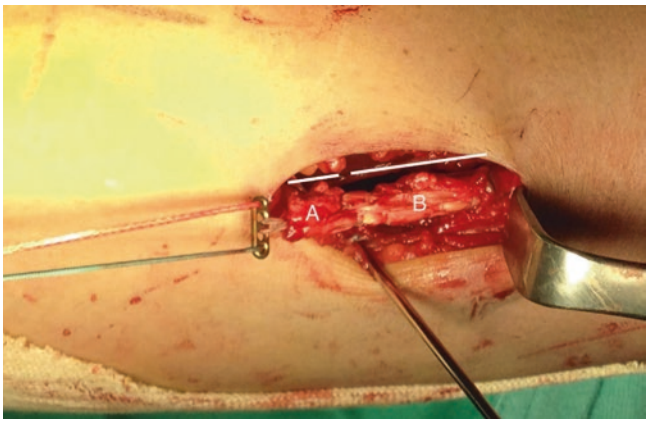


Fig. 27.3 After having completed a half tunnel of 7/8 mm always at a 45° angle, the preparation of the tendon follows. Sutures are basted using Bunnell's or Krackow's technique in zone "B" while passing through to zone "A" or sliding zone in a rectilinear manner. The sliding zone allows the tendon to undergo a shortening during the cortical button flip

carved out in the proximal to distal direction (Fig. 27.3). This broadens the entrance hole of the tendon proximally with ellipsoidal shape, with a high-speed cutter or a Citelli, to avoid possible conflicts or kinking of the repaired tendon. In this phase of the surgical procedure, it is essential to remove the fragments produced during milling with the suction so as to reduce the risk of formation of the heterotopic bone. At this point, the traction sutures of the cortical button are inserted in the slot of the guide wire which, once it crosses the soft tissues, comes out from the dorsal surface of the forearm and carries the sutures. The elbow is flexed to 100°, and the suture is pulled on with a more robust wire (traction suture) (Fig. 27.4). A second traction suture can be prepared in order to let the cortical button to flip. With the image intensifier, it is possible to check the correct tendon position. At this point of the intervention, the elbow is completely extended to control the resistance. At the end of the surgical procedure, it is important to verify the correct tension of the tendon, which passes through the center of the surgical access, taut (see Fig. 27.5). After suturing the skin and subcutaneous tissue, the elbow is immobilized in a cast for 7 days at 90° to relieve the pain.

27.6 Rehabilitation and Return to Sport

History of the treatment of distal biceps tendon lesions has evolved substantially in recent years. In fact, in 1941, Dobbie argued that surgery was not necessary to treat distal biceps lesions because it "is impractical and unwise to select a procedure more difficult, dangerous and time consuming when the same result can be obtained with less effort and without risk of serious complications" (Dobbie 1941).

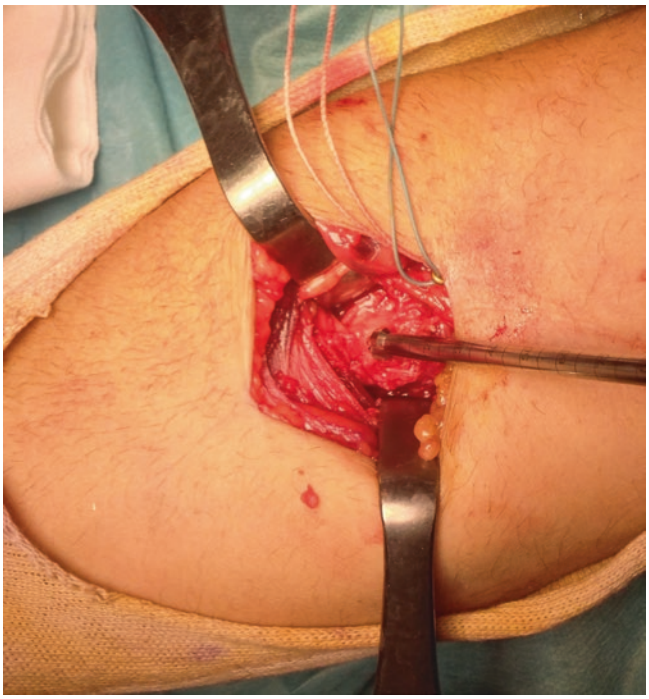


Fig. 27.4 After having completed a half tunnel of 7/8 mm always at a 45° angle, the preparation of the tendon follows. Sutures are basted using Bunnell's or Krackow's technique in zone "B" while passing through to zone "A" or sliding zone in a rectilinear manner. The sliding zone allows the tendon to undergo a shortening during the cortical button flip



Fig. 27.5 At the end of the procedure, the tendon appears tight in the center of the surgical access

Conversely today there's a considerable literature in favor of surgical treatment for complete injuries of biceps distal tendon (Baker and Bierwagen 1985; Morrey et al. 1985; Chillemi et al. 2007; Hetsroni et al. 2008; Freeman et al. 2009).

The reason for this consensus is that an important deficit in elbow flexion strength (average of 30–40%) and supination strength (average of 50%) is present in case of distal biceps tendon brachii lesion (Nesterenko et al. 2010; Klonz et al. 2003) even if, actually, other studies showed that the patients with an unrepaired rupture had a significant difference in supination strength but not in flexion strength (Freeman et al. 2009).

Conservative treatment (which according to some authors results in an acceptable functional deficit and residual force) is reserved for older people and patients with poor functional requirements or when the operative risk is too high and when there is a lack of familiarity by the surgeon with the operative technique or a feeling, based on clinical examination, that the patient could recover a satisfactory force for his\her needs once acute pain is regressed (Nesterenko et al. 2010; Quach et al. 2010).

So what usually comes to the attention of the physiatrist is a young adult man, athlete or manual worker, who underwent surgery and is wearing a brace.

Even if almost all authors agree to protect the distal biceps tendon in the postoperative period with an elbow immobilization brace, there is still much conflict about the immobilization time.

Usually the patient wears a splint at 90° of flexion with the forearm supinated or in neutral position (Fig. 27.6). Immobilization time described, however, varies widely: from 1 to 6 weeks, with an average of 2 weeks. Authors who are proponents for an immediate ROM protocol pose as the only prohibition on handling objects heavier than 0.5 kg for the first 6 weeks (McKee et al. 2005; Thompson 1998; Cil et al. 2009; Cheung et al. 2005; Heinzelmann et al. 2009; Peeters et al. 2009; Strauch et al. 1997; Davison et al. 1996; D'Arco et al. 1998; Rantanen and Orava 1999).

Why are immobilization times so different from each other? The answer has to be found in fixation techniques: a study conducted to compare the different fixation techniques showed that even the weakest of these (distal biceps tendon tenodesis) requires a force to rupture still much greater than the force required for an early active mobilization (Mazzocca et al. 2007).

In conclusion, all fixation techniques have a pullout force more than sufficient to allow an early passive movement, and, among these, Endobutton could even allow an early active mobilization securely (Widmer and Tashjian 2010).

From a rehabilitation perspective, there is no significant difference neither between the one- and two-incision techniques; what effectively affects the speed of postoperative mobilization is the quality of the bone and the manner in



Fig. 27.6 Patient wearing an elbow splint at 90° of flexion and forearm supinated

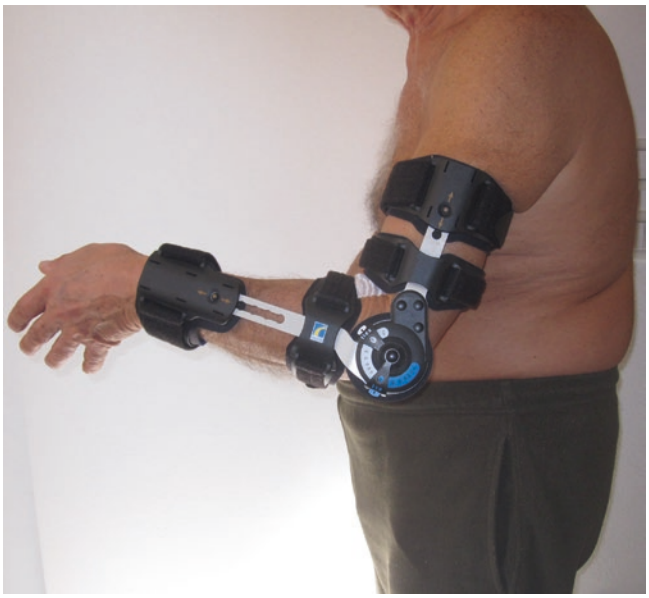


Fig. 27.7 Patient wears elbow splint during active movements of fingers and wrist

which the tendon is attached to the tuberosity. In fact, if the patient has osteoporotic bone or if tendon augmentation has been used, therapy may be slower (Blackmore et al. 2006).

After a 2-week immobilization period, splint is periodically removed to regain range of movement (ROM) performing an active extension and a passive (or gravity-assisted) flexion movement. Patient is advised to avoid active supination for at least 2 weeks (Miyamoto et al. 2010) and an aggressive stretching with forearm pronated to avoid subjecting the repaired tendon to potentially dangerous stress according to the theory of distal biceps tendon mechanical impingement between the radius and ulna (Quach et al. 2010). Active movement of the fingers, wrist, shoulder, and scapula is allowed (Fig. 27.7), but the patient will be instructed to avoid end range shoulder extension together with elbow extension so as to not stress biceps repair.

After 2 weeks, passive- and active-assisted ROM exercises are gradually performed progressively increasing by about 15° per week the splint extension block. In this way, ROM is complete in about 6 weeks (Miyamoto et al. 2010; Blackmore et al. 2006) (Fig. 27.8).

Usually scar is small (even in case of two-incision technique) and hematoma is limited, and patients do not require any manipulation therapy (Fig. 27.9). Otherwise, we can use instrumental or manual therapy for drainage and tissue elasticizing.

Strengthening rehabilitation phase starts at the third week when active-assisted supination is allowed, while active



Fig. 27.8 Passive- and active-assisted elbow ROM exercise with splint



Fig. 27.9 Small surgery scar usually without hematoma



Fig. 27.10 Light isometric exercise for biceps muscle in elbow flexion

elbow supination and flexion usually start from the fourth week. If needed, passive extension can begin at week 6 (Blackmore et al. 2006).

Biceps strengthening with single joint exercises starts at weeks 6–8: it is the opinion of many authors that if a full active ROM can be achieved in the fourth or fifth postoperative week, some gentle active exercises for biceps can be anticipated safely for the patient (Horschig et al. 2012).

We start with light isometric exercises in supination and flexion: these exercises are very important because they stimulate the activity of low intensity but long term of the muscle (Hurov 1996) (Fig. 27.10).

Isotonic exercises start later, in the eighth–tenth week, and progress from concentric to eccentric (Fig. 27.11a–f) to plyometrics. Velocity training and resisted activities against body weight are recommended at the end of the rehabilitation period to enhance the synergistic activation, timing, and coordination of elbow muscles (Garrett et al. 1988).

Especially for athletic patients is absolutely important an adeguate reinforcement of the core and complementary exercises of rhythmic stabilization and proprioception to restore the pre-injury sport level.

Activity is unrestricted after 5 months from surgical repair.

Nonoperative treatment consists of temporary immobilization, pain control, and physiotherapy.

Some isometric exercises for the wrist, forearm, and elbow can start about at week 4 if the patient is asymptomatic; otherwise we wait until the sixth week.

Symptoms attributed to decreased strength and endurance may persist with repetitive elbow flexion and supination. Fatigue subjective sensation probably depends on starting elbow activity from a lower maximum initial torque, and it is not in correlation with the time elapsed from injury. So endurance doesn't worsen or improve over time. For this reason, therapy should be direct to improve the strength of intact elbow flexors and supinators rather than to improve endurance (Nesterenko et al. 2010).

A partial rupture of the distal biceps tendon is uncommon. Initial treatment is usually nonoperative, but the patient must be advised that the lesion may progress to a complete rupture and about the possible persistence of pain in more strenuous activities. Often, partial rupture becomes asymptomatic within 6 weeks, but if symptom persists with or without functional limitation in elbow flexion and supination, surgical intervention should be considered.

Conservative treatment consists in anti-inflammatory medications, ice or cryotherapy, and functional rest. The elbow is immobilized for the first week and then a dynamic brace is worn for 6–8 weeks. It's very important to explain to the patient that a period of activity modification is necessary for an additional 3 weeks during which the patient is dedicated to the gradual recovery of motion and elbow strength.

Within 4 months, the patient usually recovers a fully pre-injury functional activity (Vidal 2004) .

27.7 Complications

Complications are mainly of two types: heterotopic calcification or radioulnar synostosis that could lead to reduced joint mobility or, most frequently, nerve complications charged to the lateral cutaneous nerve, rear intraosseous



Fig. 27.11 (**a**–**f**) Eccentric exercise for biceps muscle with light weight: patient is seated. He keeps the weight with the hand of the operated limb with the elbow flexed and resting on a support. He raises the weight by flexing dorsally the wrist using the healthy limb hand and then actively controls the weight slow downhill only using the operated limb

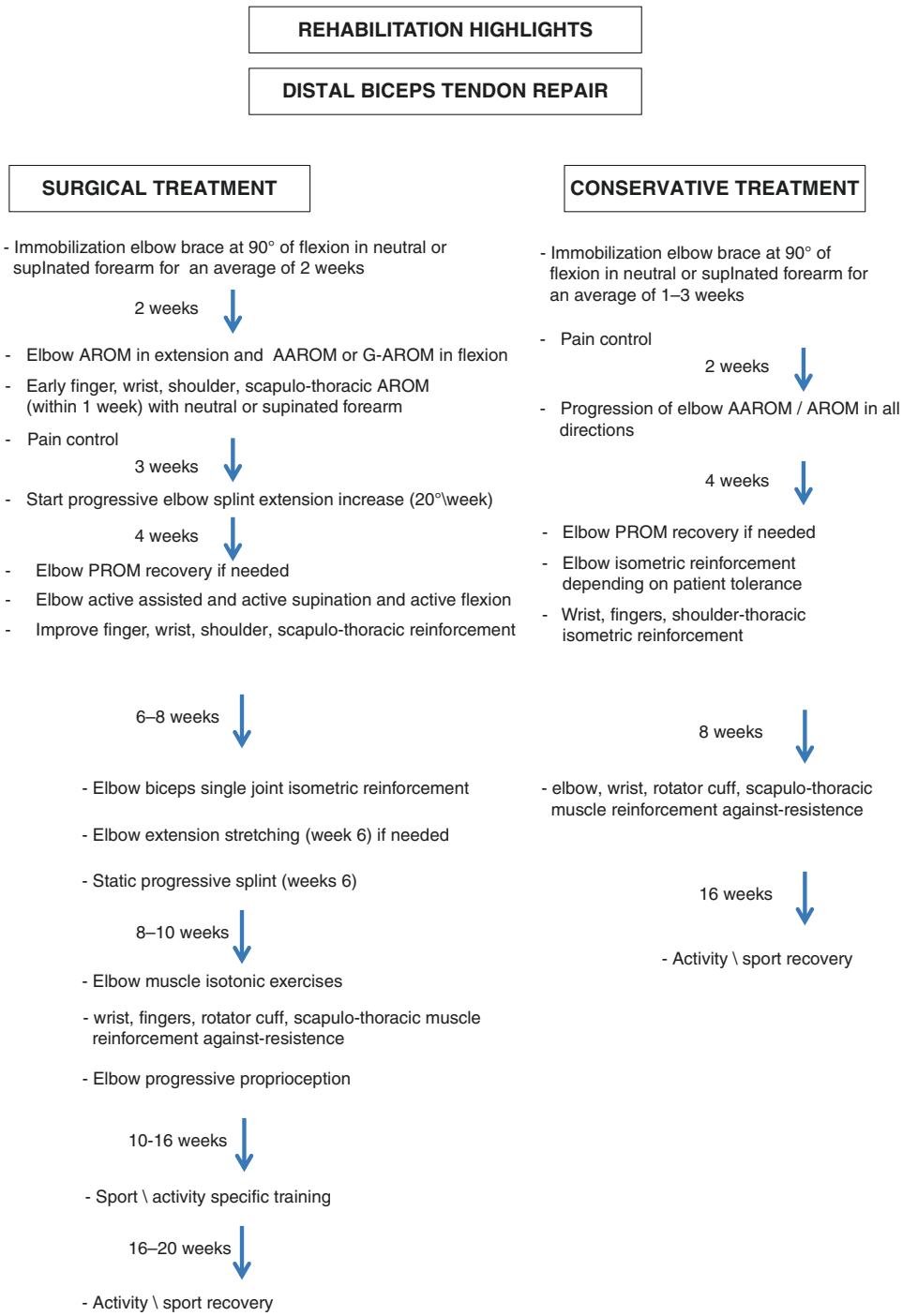
nerve, or radial nerve. Superficial infections, deep infections, or recurrence of tendon rupture are less frequently observed.

Watson et al. (2014) in his 2014 systematic review reported a percentage of 24% of complications in 498 elbows operated with several techniques, the most frequent being the neuropraxia of the lateral antebrachial cutaneous nerve (9.6%), followed by the formation of heterotopic ossification 4.4%, a 3.2% rigidity, a 1.6% recurrence of tendon tear, a 0.6% infections, and a synostosis at 0.8%. The authors concluded that there are no significant differences between making one or two incisions but that those techniques that foresee fixation with cortical button and bone tunnel are the safest ones. Furthermore, they have found an absence of synostosis in the technique with using only one incision.

Conclusions

Distal biceps tendon repair is a safe, replicable technique that offers optimal clinical results. Both the techniques with one and two incisions show an equally safe treatment in terms of clinical results.

Patients gain full recovery of elbow articulation, strength, and resistance, with very low risk of complications.



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Triceps Ruptures

28

Giuseppe Giannicola, Gianluca Bullitta, Federico M. Sacchetti, David Polimanti, and Marco Scacchi

28.1 Introduction

The triceps brachii, which is the main extensor muscle of the elbow, plays a key role in normal upper extremity function. Distal rupture of the triceps tendon is a fairly rare injury. When they reviewed 1014 tendon ruptures, Anzel et al. reported a prevalence of 0.8%, while Mair et al. reported 21 cases of triceps rupture over 6 years in the National USA Football League (Anzel et al. 1959; Mair et al. 2004). However, Koplas et al. recently observed a marked prevalence of triceps tendon tears (3.8%) as assessed by MRI, which indicates that the number of triceps tendon injuries is likely to be underestimated in imaging studies and the orthopedic literature and that this type of lesion is often unrecognized (Koplas et al. 2011).

Distal triceps tendon tears occur more often in men, above all in professional sports players. Although the average age at which such tears occur is about 35 years, they have been reported in every age group, including children and elderly subjects (Kandemir et al. 2002; Vidal et al. 2004; Weistroffer et al. 2003; McCulloch et al. 2008).

In order to help the orthopedic sports physician to evaluate and treat triceps tendon injuries, this chapter considers the anatomy, etiology, clinical presentation, diagnostic protocols, conservative and operative treatments, and outcomes in both partial and complete injuries.

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28.2 Anatomy and Function

The "triceps brachii" is a pennate muscle. Its name derives from its tripartite origin comprising the lateral, long, and medial heads. The triceps runs the entire length of the posterior humerus and is the only muscle in the posterior compartment of the arm. As described by Gray, the lateral head originates in three sites, i.e., the posterior humerus between the teres minor insertion and the superior aspect of the spiral groove, the lateral border of the humerus, and the lateral intermuscular septum (Gray 1959); the long head originates at the infraglenoid tuberosity, at the point where the scapula joins the shoulder capsule. The medial (or deep) head originates on the posterior humerus distal to the spiral groove, medial humerus, and medial intermuscular septum. Each head thus originates distal to the other, and the areas of origin become increasingly large. The long and lateral heads, which are superficial to the deep medial head, blend in the midline of the humerus, thereby forming a common tendon or intermuscular septum, covered by the triceps aponeurosis (Fig. 28.1); the latter structure is occasionally absent. The mean length of the superficial tendon is 15.2 cm (range, 13.3–17.1) when measured from the tip of the olecranon to the most proximal point of the tendon medially (Keener et al. 2010).

The triceps insertion may be considered a wide area or footprint, rather than a focal point on the olecranon. In a study on cadavers, the triceps footprint was found to cover an extensive area of the supero-posterior aspect of the olecranon, with a mean surface area ranging from 466 mm^2 to 646 mm^2; moreover, the study found that it started 12 mm distal to the tip of the olecranon and blended with the posterior capsule (Yeh et al. 2010a). The tendon width at the insertion exceeds that of the olecranon, thus indicating that the distal triceps does not end at a point insertion, but extends well beyond the olecranon tip distally and includes the medial, lateral, and posterior borders of the olecranon.

The extensor mechanism of the elbow is made up of two components: the triceps tendon itself (the confluence of the tendon from all three heads inserting on the olecranon) and

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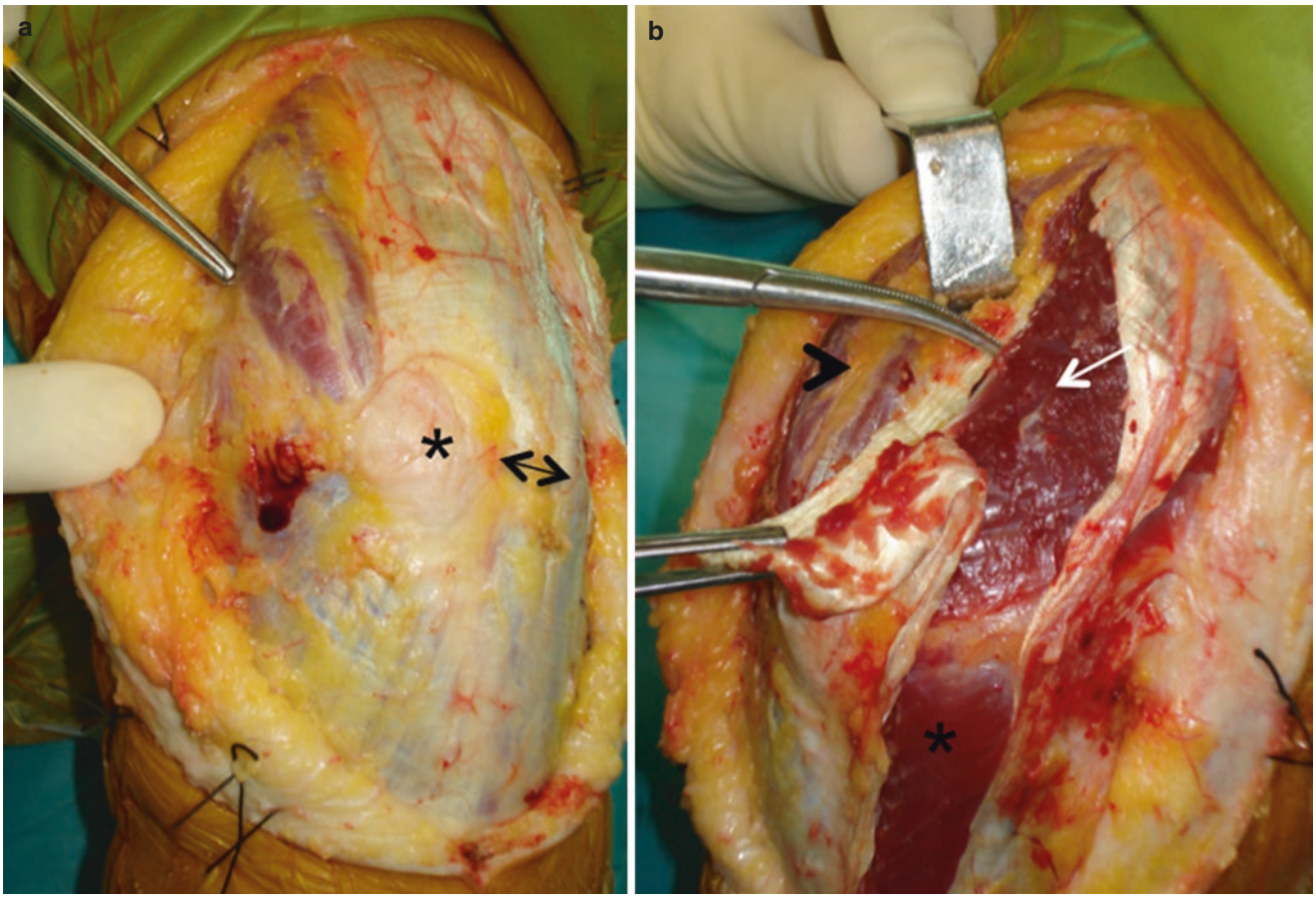


Fig. 28.1 (**a**) Posterior aspect of the elbow, showing the triceps brachii muscle where the triceps aponeurosis is well represented. The *asterisk* indicates the olecranon, whereas the *double-headed arrow* shows the lateral expansion of the aponeurosis. The surgical clamp indicates the ulnar nerve. (**b**) The triceps aponeurosis was detached and reflected, and the common tendon was revealed, as indicated by the Klemmer. The *white arrow* indicates the lateral head of the triceps, whereas the *asterisk* indicates the anconeus muscle. The *arrowhead* indicates the long head of the triceps brachii which is located medially to the tendon

the lateral and medial triceps expansions. The mean length and width of the distal tendon at the level of insertion are 20.52 mm (SD 2.02) and 22.65 mm (SD 2.40), respectively (Yeh et al. 2010a). The lateral triceps expansion fans out laterally from fibers of the triceps and blends into the fascia of the anconeus muscle, the extensor carpi ulnaris muscle, and the posterior border of the ulna; moreover, the triceps expansion inserts on the antebrachial fascia of the forearm distally (Madsen et al. 2006). The expansion length from a line between both epicondyles to its insertion is 4.02 cm (range 2.3–6.0 cm) (Windisch et al. 2006). Owing to its wide lateral insertion, concomitant repair of the triceps expansion is often required in cases of triceps rupture. Although the triceps may be able to compensate for injury to the triceps expansion (e.g., by sacrificing the triceps expansion in the classic intra-articular olecranon osteotomy exposure), the triceps expansion is unable to compensate fully for injury to the triceps in injuries such as triceps avulsion.

The insertion of the medial aspect of the triceps expansion lies on the posterior crest of the ulna, adjacent to the medial head (Yeh et al. 2010b). Hypertrophy affecting the medial head of the triceps muscle may cause ulnar nerve impingement, a condition observed in weight lifters (Yeh et al. 2010b). The distal portion of the medial head has a distinct muscle belly, while the deep insertion consists of muscle combined with a small amount of tendon (Madsen et al. 2006). Upon gross examination, the tendon of the medial head of the triceps is smaller and lies deep in relation to the tendon of the long and lateral heads. There is always a thin fascial layer that separates the long and lateral heads from the deeper medial. This fascial plane has been defined clearly and can easily be dissected. The deep tendon is clearly visible once the overlying conjoined tendons of the long and lateral heads of the triceps have been divided longitudinally. The histological analysis does not, however, detect any separation between the deep and superficial tendons at their insertion on the olecranon (Madsen et al. 2006).

The triceps is innervated by the radial nerve (C6–C8). The function of the triceps is mainly to extend the forearm at the ulno-humeral joint. However, since it originates at the infraglenoid tuberosity, the long head of the triceps is also presumed to contribute to arm adduction and extension. A critical

aspect of triceps motor function is the overall muscle-tendon length of this triceps; indeed, a biomechanical study has shown that a 2-cm reduction between its origin and insertion reduces its extension strength by 40% (Hughes et al. 1997). Gerbeaux et al. studied the lever arm of the triceps muscle in cadaveric specimens (Gerbeaux et al. 1996). They adopted the long head of the triceps as their model, showing that the lever arm value of the triceps ranged from a maximum of about 0.5 radians (45°) to a minimum of about 2 radians (180°). This finding indicates that the triceps lever arm is greatest when the elbow is fully flexed. Although the triceps was fixed in that experiment, it is noteworthy that the scapular insertion of the long head of the triceps provides more freedom, thus producing a potentially more dynamic system in vivo. The length of the triceps lever arm indicates that its greatest degree of strength is exerted in flexion, though the separation of individual sarcomeric units is known to substantially weaken the triceps when it is stretched; the triceps therefore exerts the greatest degree of power when the elbow is closest to full extension (Gray 1959).

28.3 Etiology and Mechanism of Injury

Considerable force is required to rupture a normal triceps tendon. Direct posterior force on the elbow and weight lifting are among the two most common mechanisms (Kandemir et al. 2002; Van Riet et al. 2003; Daglar et al. 2009; Duchow et al. 2000; Harris et al. 2004; Weng and Wang 2006). Other causes that have been documented include seizures, swinging a baseball bat, pitching, punching, volleyball serving, motor vehicle accidents, and hammering (Sanchez-Sotelo and Morrey 2002; Farrar and Lippert 1981; Searfoss et al. 1976; Sherman et al. 1984; Brumback 1987; Gilcreest 1925; Haldeman and Soto-Hall 1935; Newmark et al. 1985). When direct trauma is excluded as a cause, the biomechanics of injury are comparable in each of these mechanisms. Uncoordinated contraction of the triceps against the flexed elbow, associated with a deceleration-like impact, overloads the tendon eccentrically (Mair et al. 2004; Vidal et al. 2004; McCulloch et al. 2008; Van Riet et al. 2003; Daglar et al. 2009; Weng and Wang 2006; Sanchez-Sotelo and Morrey 2002; Brumback 1987; Kibuule and Fehringer 2007; Singh and Pooley 2002; Rettig 2002). Although the tendon can withstand three times the force of tetanic contraction (Gupta and Murthi 2010), a number of factors can alter its structural integrity and reduce its maximum load capacity (Van Riet et al. 2003; Sanchez-Sotelo and Morrey 2002). Distal triceps tendon ruptures are even known to occur spontaneously or following minimal trauma in patients with concomitant significant systemic or local conditions. Pathological changes resulting in a weak tendon are believed to be the mechanism underlying the vast majority of tendon ruptures. Most reports have associated triceps tendon rupture with anabolic steroid use or steroid treatment, renal osteodystrophy, hyperparathyroidism, hypocalcemic tetany, Marfan syndrome, osteogenesis imperfecta, rheumatoid arthritis, lupus, or type I diabetes (Mair et al. 2004; Kandemir et al. 2002; McCulloch et al. 2008; Van Riet et al. 2003; Harris et al. 2004; Sanchez-Sotelo and Morrey 2002; Kibuule and Fehringer 2007; Rettig 2002; Tsourvakas et al. 2004; Clayton and Thirupathi 1984; Lambert et al. 1995). Connective tissue degeneration due to ciprofloxacin has also been reported to increase the risk of tendon rupture (McCulloch et al. 2008).

Professional football players and bodybuilders are believed to be more at risk for rupture than the general population, possibly on account of their training regimen, of locally injected steroid use in case of olecranon bursitis and of the violent nature of the sport they play (Mair et al. 2004). Adolescent athletes with incompletely fused or recently fused physes may also be susceptible to triceps tendon rupture, though this is an extremely rare event (Vidal et al. 2004).

28.4 History and Physical Examination

A history of eccentric loading in flexion against the triceps contracture (e.g., fall or weight lifting) associated with acute pain and weakness yields the most reliable diagnosis. The patient presents with pain and swelling over the posterior aspect of the elbow, though the pain is often non-dysfunctional. Consequently, patients sometimes underestimate the severity of the trauma after the acute event and wait several weeks before seeing the orthopedic surgeon, to whom they complain of reduced strength and persistent pain.

The physical examination in the acute setting reveals tenderness to touch, swelling, muscle spasm, and ecchymosis. Although a defect proximal to the olecranon may be palpable, in partial tears and obese patients, it tends not to be (Sharma et al. 2005). An inability to actively extend against gravity is a pathognomonic sign of complete rupture. However, complete tears do not always prevent active extension against resistance owing to an intact lateral expansion or a compensating anconeus muscle (Sharma et al. 2005; Petre et al. 2011). In such cases, assessing the reduction in strength against gravity or resistance starting from maximum elbow flexion may help.

Viegas recommends the use of a modified Thompson squeeze test as a clinical diagnostic tool (Viegas 1990). During this passive extension test, the patient lies prone with the elbow at the edge of the examination table. The forearm is allowed to hang over the table edge in such a way that it is flexed in a relaxed position at 90°. When the examiner squeezes the triceps muscle firmly, any patient with complete disruption of the triceps itself and lateral expansion will not, according to those authors, be able to extend the elbow against gravity. No study has yet assessed the sensitivity and specificity of this diagnostic test.



Fig. 28.2 Clinical test used for the diagnosis of triceps tendon tear. (**a**) In case of distal triceps tendon rupture, a palpable defect proximal to the olecranon may be apparent. This evidence of rupture is called "gap sign." (**b**) The "Viegas squeezing sign." (**c**) The inability to actively extend against gravity is usually a sign of complete rupture with involvement of the lateral expansion, whereas (**d**) the ability to actively extend against gravity associated with the inability to extend against resistance may be a sign of partial rupture. (**e**) The "posterior hook sign"

In one unpublished study, Giannicola proposed a new diagnostic test for triceps tendon rupture referred to as the "posterior hook test." This test is similar to the hook test for distal biceps avulsion described by O'Driscoll et al. (O'Driscoll et al. 2007). The posterior hook test is performed with the examiner standing behind the patient, who is asked to contract and relax the triceps muscle with the forearm fully extended. The examiner inserts his/her index finger into the superomedial side of the olecranon, laterally to the ulnar nerve, and attempts to hook the medial portion of triceps tendon. In contrast to O'Driscoll's test, when the posterior hook test is performed in healthy patients, it is impossible to insert the finger beneath the tendon during the triceps contraction; indeed, the examiner encounters a cord-like structure that belongs to the triceps tendon and prevents the index finger from being slid in a medial-to-lateral direction along the humeral bone surface. By contrast, this cord-like structure is not encountered in patients with a triceps tendon tear, and the examiner's finger can slide as far as the central and lateral bone surface of the distal humerus. In Fig. 28.2 the most tests utilized by authors are shown.

Diagnostic difficulties, low clinical suspicion, and underestimation of injury severity may delay both the diagnosis and surgical intervention, which may in turn prolong the disability (Van Riet et al. 2003; Sharma et al. 2005). Diagnosis of triceps tendon rupture is associated with a high degree of suspicion; indeed, almost 50% of acute triceps ruptures in one recent

study were misdiagnosed initially (Van Riet et al. 2003). With regard to chronic tears, the most common complaints are pain, mild extension lag, and weakness. A lack of swelling or of acute pain increases the reliability of the clinical examination.

28.5 Imaging

AP and lateral radiographs of the affected elbow are always indicated. Lateral radiographs sometimes reveal the presence of small olecranon avulsion fragments, which are referred to as the "flake sign" and are considered to be almost pathognomonic of a triceps tendon rupture (Fig. 28.3) (Vidal et al. 2004; Rettig 2002). Likewise, the presence of dystrophic calcification or heterotopic ossification (a sign of tendon degeneration) at the level of the triceps tendon insertion should be interpreted as a sign of likely triceps rupture. When Giannicola analyzed the tendons of ten patients with a triceps tear, metaplastic bone tissue was found within the tendon in 20% of the cases. In particular, the histological analysis yielded a microscopic picture of enthesopathy characterized by degenerative changes, which included thinning, fragmentation and tearing of collagen fibers, increased cellularity and vascularization, as well as focal areas of ossification associated with chronic inflammatory infiltrates (Fig. 28.4).



Fig. 28.3 A standard LL radiograph showing a small avulsion fragment from the olecranon (*arrow*) named "flake sign"

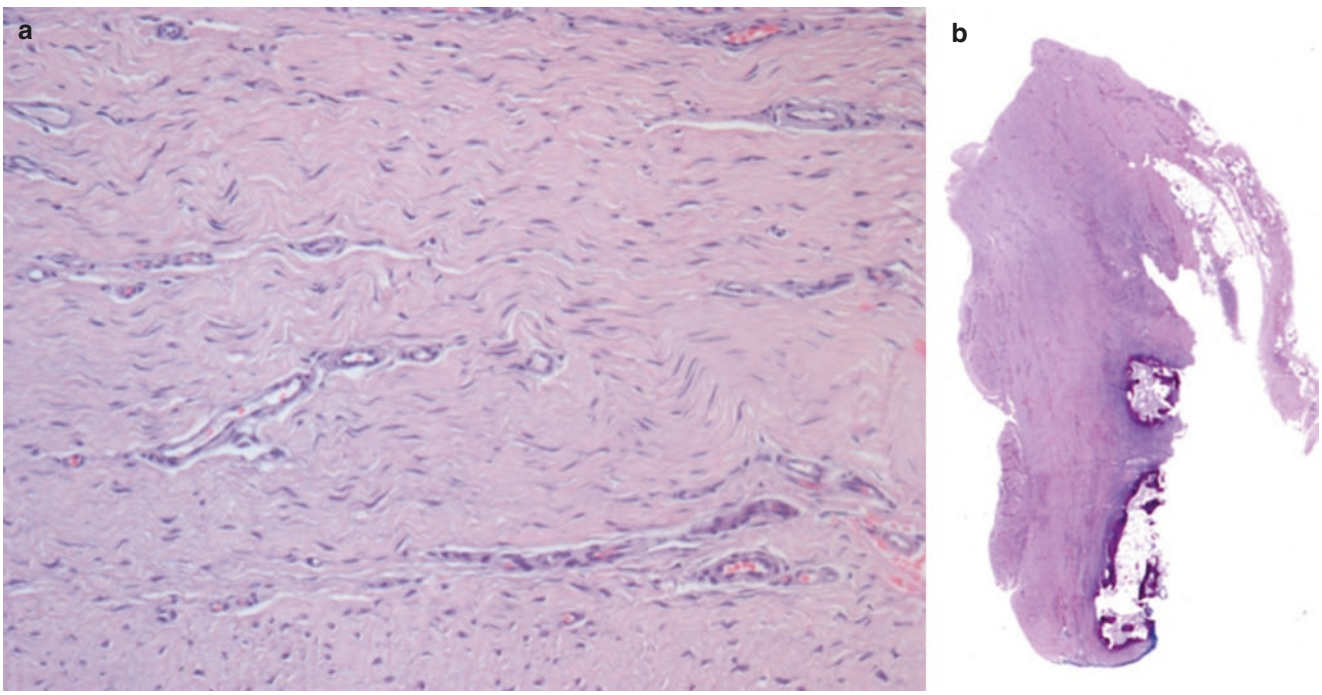


Fig. 28.4 Histological sections of a ruptured tendon showing (**a**) increased cellularity and vascularization along with chronic inflammatory infiltrates and (**b**) the presence of metaplastic osseous and cartilaginous inclusions

MRI and ultrasonography may be useful in challenging cases and when planning surgery to determine the site and severity of the tear (Kaempffe and Lerner 1996; Zionts and Vachon 1997; Kijowski et al. 2005). Axial and sagittal MRI is considered the gold standard because it reliably demonstrates the integrity of the triceps tendon (Mair et al. 2004; Van Riet et al. 2003; Blackmore et al. 2006; Thornton et al. 2003). Furthermore, MRI distinguishes between partial and complete rupture as well as between superficial and deep tears of the triceps tendon and can be used to determine the degree of retraction of a tendon that has been completely torn. Partial rupture is characterized by a small fluid-filled defect within the distal triceps tendon (bright area on T2-weighted images), with edema extending to the surrounding subcutaneous tissues. By contrast, complete rupture of the triceps tendon is characterized by a large fluid-filled gap between the distal end of the triceps tendon and the olecranon process (Kijowski et al. 2005). The distal edge of the torn tendon is retracted and signal intensity is heterogeneous. In the authors' clinical experience, T2-weighted images on the sagittal plane with the elbow flexed at about 90° are the most reliable sequences from a diagnostic point of view.

28.6 Associated Lesions

Several authors have described the association between triceps tears and concomitant injuries. The most frequent concomitant lesion is the radial head fracture, probably because of the similar underlying mechanism of injury (Levy et al. 1978; Levy et al. 1982; Yoon et al. 2012). Levy et al., who studied a large series (15 patients) in whom this association was present, found that the mechanism underlying the trauma in the majority of patients (12/15) was a fall on an outstretched arm without direct injury to the elbow (Levy et al. 1978; Levy et al. 1982). Recently, Yoon et al. described four patients with triad injury consisting of triceps avulsion, radial head fracture, and medial collateral ligament lesion (Yoon et al. 2012). Other lesions reported to be associated with triceps tears include ulnar collateral ligament laxity (Tatebe et al. 2007), ulnar nerve compression due to hematoma (Duchow et al. 2000), radial nerve compression due to compartment syndrome (Brumback 1987), wrist fracture (Harris et al. 2004), ulnar collateral ligament avulsion with flexor/pronator group injury (Daglar et al. 2009), and distal humerus fracture (Gupta and Murthi 2010).

28.7 Classification

There is no widely accepted classification system for distal triceps rupture. We used the classification of Giannicola (Fig. 28.5) (Giannicola et al. 2012), which describes these injuries on the basis of (1) the *location* of the tear (muscle belly, musculotendinous junction, tendinous body, tendinous insertion), (2) the *depth* of the tendinous lesion (superficial tear, deep tear and full thickness tear), (3) the *degree* of the tendinous and/or muscular tear (complete or partial), and (4) the *involvement of the lateral expansion* (intact or torn).

The majority of studies in the literature have described triceps tears only as either partial lesions or as a complete rupture in the muscle belly, musculotendinous junction, or tendinous insertion, thereby preventing any reliable comparison of the results of the various studies. A more standard classification is warranted in future studies so as to allow diagnostic and therapeutic guidelines to be drawn up.

In a particular subgroup of patients with triceps tear, part of the olecranon is avulsed with the tendon (Kibuule and Fehringer 2007; Viegas 1990; Tarallo et al. 2015). This is most often observed in skeletally immature patients in whom the ossification center of the olecranon has not yet fused; by contrast, the fracture of the proximal part of the olecranon is the lesion that is most frequently associated in adults. We believe that these injuries should be classified, respectively, as detachment of the ossification centers and as olecranon fractures, as opposed to triceps ruptures. Tendon degeneration, which is the leading predisposing factor in such injuries, is indeed highly unlikely in patients whose skeleton is immature. In our opinion, only triceps lesions characterized by small bone avulsion fragments of the olecranon footprint (i.e., the flake sign) should be considered true triceps tendon tears in adults because most of these ruptures occur at the degenerated tendon insertion. We thus decided to exclude such lesions from this chapter.

28.8 Treatment

No guidelines on the treatment of tendon injuries of the triceps exist. This is due to a number of factors, such as the relative rarity of this type of injury and the lack of a widely accepted classification. Consequently, few studies and RCTs have been conducted on this topic, and those that have are retrospective and founded on a low level of evidence.

Triceps tears are normally managed according to the tear location and severity. In nonprofessional sports players, some authors have reported that the nonsurgical treatment of any acute tear that affects less than 50% of the triceps tendon (Vidal et al. 2004), along with the belly muscle, triceps aponeurosis, and lateral expansion lesions, leads to satisfactory results in the majority of cases, whereas other authors believe that this type of lesion requires surgery to ensure a quick recovery of elbow function, particularly in athletes (Mair et al. 2004; Strauch 1999). There is instead a wider consensus in the literature regarding the need to surgically treat

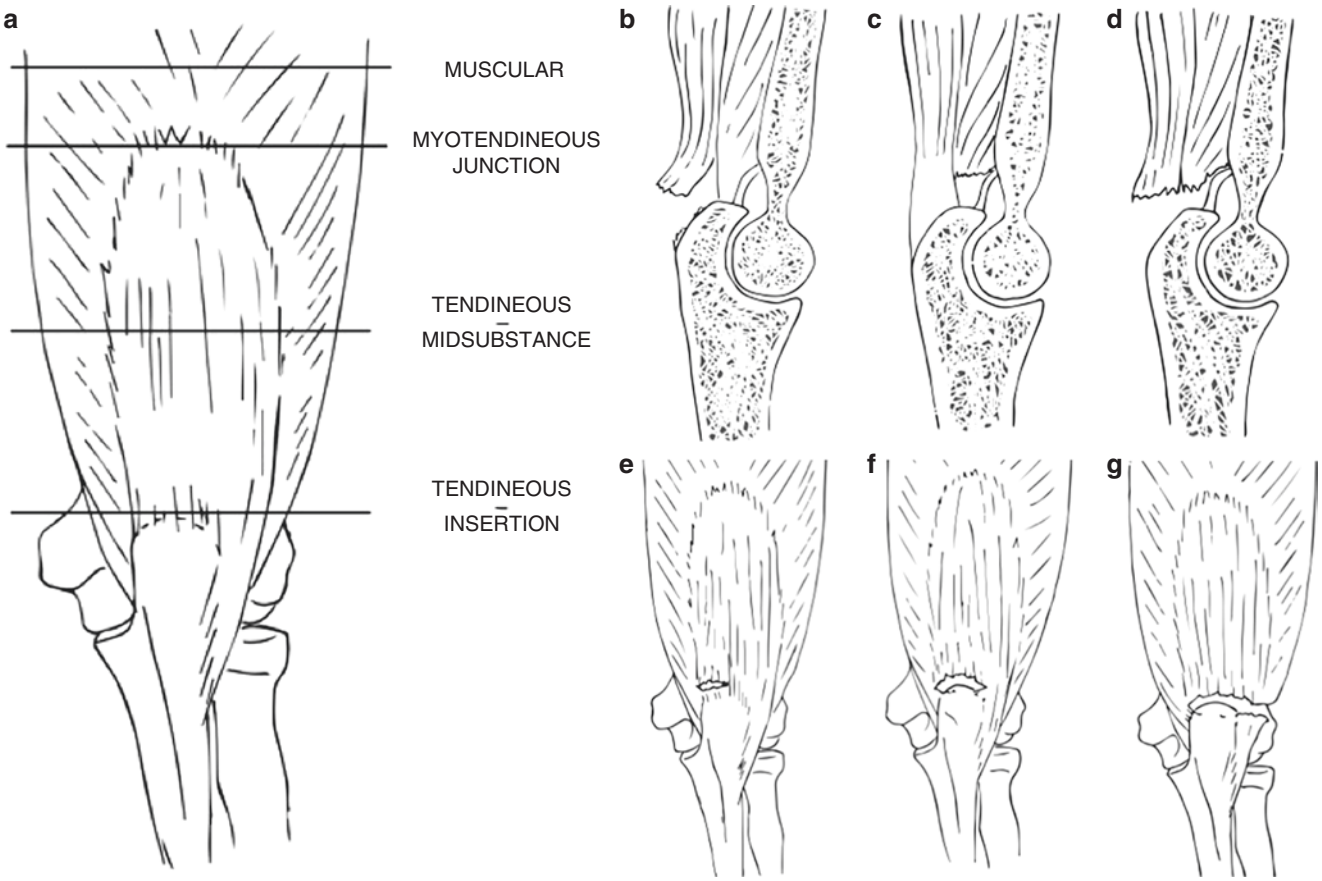


Fig. 28.5 Figure showing the Giannicola's classification of triceps ruptures: (**a**) the tear may occur at the level of muscle belly, musculotendinous junction, midsubstance of the tendon, and at the level of the insertion; the depth of the tendinous lesion can involve the superficial layer with the isolated tear of lateral and long heads tendon (superficial tear) (**b**); the deeper layer (medial head) may be involved alone (deep tear) (**c**) or in association with the superficial tendinous layer (full thickness tear) (**d**). The degree of the tendinous or muscular tear allows to divide the triceps lesions in partial (**e**) or complete (**f**) tear; the extension of the tendon lesion to the lateral expansion categorizes the tears with or without the involvement of lateral expansion (**g**)

cases of complete or near-complete tears of the triceps tendon in both low- and high-demand patients (Van Riet et al. 2003; Sharma et al. 2005; Pina et al. 2002).

28.9 Conservative Treatment

Partial triceps tendon ruptures have traditionally been treated non-operatively, though this is not a consensus opinion. Some authors believe that partial tears of the muscle belly, musculotendinous junction and tendon can be managed non-surgically, especially those in low-demand patients (Vidal et al. 2004; Harris et al. 2004). Bos et al. described a patient with a partial injury who was treated with posterior splinting of the elbow in 30° flexion for 6 weeks, followed by active movement (Tarallo et al. 2015). Full ROM and normal strength were achieved, respectively, after 3 and 6 months, with the MRI performed at 3 months highlighting the return of fibrous tissue continuity. Farrar and Lippert also reported a good outcome in a patient whose elbow was splinted at 30° flexion for 3 weeks, with full ROM and extensor strength in this patient being achieved at 9 months (Farrar and Lippert 1981). Harris et al. described a patient with a 70% right-sided rupture and 50% left-sided rupture, as detected by MRI (Harris et al. 2004). As this patient refused to be immobilized, arm slings were used. The patient started weight lifting 4 weeks after injury and had regained normal function by 41 weeks.

According to other authors, it is not always possible to predict the healing of partial tears of the tendon insertion (Morrey and Morrey 2009). Although such tears may appear to be healing initially and be associated with reduced pain and improved function, the patient will become symptomatic as activity increases; it is thus necessary to observe how much progress is made over a 6- to 12-week period before deciding whether a patient needs surgery (Morrey and Morrey 2009). Lempainen et al. reported that conservative treatment of the partial musculotendinous junction failed in

six athletes, who subsequently underwent delayed surgical treatment (Lempainen et al. 2011). Delayed surgical treatment in conservatively treated partial tears has been reported in the general population by other authors (Van Riet et al. 2003; Weng and Wang 2006; Kibuule and Fehringer 2007; Clayton and Thirupathi 1984; Inhofe and Moneim 1996; Athwal et al. 2009).

Mair et al. found that six out ten professional football players with partial tears who were treated nonsurgically did not complain of any residual pain or weakness (Mair et al. 2004). Three of the players were treated by bracing for the rest of the season, with surgery being performed at the end to correct any residual pain and weakness; one player sustained a complete rupture upon returning to play despite the bracing. The results of that study show that surgery was required in 40% of the patients treated conservatively. This indicates that although treatment should be tailored individually to the needs of each patient, surgery is recommended in professional sports players, even in cases in which the detachment is only partial. For these reasons, the authors of the aforementioned study recommend a non-operative approach to professional sports players only in cases of tendon "strain", in which physical activity alone leads to the gradual resolution of symptoms.

To sum up, conservative treatment may be performed in partial tears of the triceps tendon, with patients generally being able to return to play 4–6 months later, when symptoms have resolved and strength has returned to almost normal. However, close observation of the patient is essential in this period to exclude any worsening of the lesion; highly negative prognostic signs are the persistence of pain and weakness.

28.10 Surgical Treatment

Primary repair is recommended in patients with acute and chronic complete or near-complete triceps tendinous tears characterized by a significant loss of triceps strength, as well as in a complete muscle belly or musculotendinous junction with a significant gap. As mentioned above, surgical treatment may also be suited to acute partial tears in high-demand patients or in cases in whom nonsurgical treatment failed. Surgical treatment is contraindicated in patients with serious comorbidities or who are medically unstable, as well as in those who cannot cooperate during rehabilitation or display poor compliance.

Although primary repair should be performed as early as possible, it has been performed as late as 8 months after injury (Vidal et al. 2004; Van Riet et al. 2003; Inhofe and Moneim 1996). Van Riet et al. reported good results in all eight patients who presented within 3 weeks of injury and underwent primary repair but in fewer than half of those (6/15) who presented after 25 days (Van Riet et al. 2003). These findings indicate that when intervention is prompt, primary repair can be performed in all cases, thereby avoiding challenging reconstruction procedures.

A number of procedures have been described for primary repair, including reinsertion of the triceps tendon using the transosseous technique and suture anchors (McCulloch et al. 2008; Yeh et al. 2010a; Van Riet et al. 2003; Duchow et al. 2000; Farrar and Lippert 1981; Pina et al. 2002). Relatively little is instead known about the procedures used for belly muscle or musculotendinous junction repair because such lesions are extremely uncommon (Singh and Pooley 2002). The tendon insertion tear technique that has been investigated most is a direct attachment with #2 or #5 nonabsorbable cross-suture (Bunnell or Krackow whipstitch technique) through cruciate drill holes in the olecranon (McCulloch et al. 2008; Yeh et al. 2010a; Van Riet et al. 2003; Duchow et al. 2000; Farrar and Lippert 1981; Tsourvakas et al. 2004). A less common surgical procedure that has been adopted for primary repair is the suture anchor technique (Pina et al. 2002). This procedure entails positioning the anchors in the middle tendon footprint and tying them to locking stitches applied to either side of the tendon. In a recent biomechanical study, Yeh et al. described the "anatomic triceps tendon footprint repair"; the authors used suture anchors to build a suture bridge (double row) so as to restore the pre-injury anatomy and create a more extensive area of tendon-bone contact (Yeh et al. 2010a). According to the authors of that study, this technique not only restores the pre-injury anatomy more effectively than other types of repair but also reduces repair-site motion.

The techniques most often used to treat intratendinous tears, which are proximal to the insertion, are the same as the cross-suture techniques used to treat tendon insertion tears (Van Riet et al. 2003). Fewer data are available on the treatment of musculotendinous and intramuscular tears. Musculotendinous junction lesions generally extend more toward the medial part of the muscle, though they sometimes also affect the belly of the triceps muscle (Aso and Torisu 1984; Wagner and Cooney 1997; O'Driscoll 1992). Lempainen et al. obtained satisfactory results, after the failure of conservative treatment, in six athletes with such lesions treated surgically by means of side-to-side suture (Lempainen et al. 2011). However, management of triceps rupture at the myotendinous junction can be challenging because of the poor quality of the tissue available for primary repair; Wagner and Cooney even recommended the use of the V-Y triceps tendon advancement technique with plantaris augmentation to effectively repair this type of lesion (Wagner and Cooney 1997).

The information available on different types of intramuscular tears and their treatment is scarce, and the best approach is still debated. Two of the seven cases reported in the literature presented a complete rupture of all three heads of the triceps (Singh and Pooley 2002; Montgomery 1920), while the long head alone was involved in a further two of these cases (O'Driscoll 1992; Sheps et al. 1997); the medial head was involved in one of the three remaining cases (Aso and Torisu 1984), an unclearly defined partial lesion in another (Aso and Torisu 1984) and, finally, Penhallow described one patient with a complete rupture of the long head and a partial tear of the medial heads during surgery (Penhallow 1910). Four out of these cases were treated surgically with a side-to-side suture, while the remaining three did not undergo surgery. Repair could not be carried out on 1 of the 4 patients who underwent surgery because an exploration showed that the muscle was already scarred and had adhered (Aso and Torisu 1984). Singh and Pooley recommend that the extent of the injury and the functional requirements of the patient be taken into account when deciding whether conservative or surgical treatment is more appropriate for intramuscular tears (Singh and Pooley 2002).

28.11 Primary Repair: Surgical Technique

The surgeon may decide to place the patient in the supine, prone, or lateral decubitus position, under general or local anesthesia. In the prone position, which is our decubitus of choice, the upper extremity is draped free and hung over an arm rest in such a way as to allow the elbow to be manipulated comfortably. As the silicone ring tourniquet allows the operating field to be extended proximally, it may be preferred to the pneumatic tourniquet; this may prove particularly useful in chronic tears, in which extended proximal release is needed to mobilize the tendon adequately. A posterior incision is performed just lateral or medial to the olecranon. The ulnar nerve is identified and protected, but not decompressed or transposed, particularly in acute cases. The triceps tendon lesion is identified by dissection, performed through skin and subcutaneous tissues; identification of chronic triceps tear is always more challenging because bursal and fibrous tissues tend to cover the tendon. Once this pathological tissue has been removed, the ruptured tendon edges are exposed and debrided back to the normal-appearing tendon, thereby allowing the tendon tear to be evaluated in terms of tissue quality, size and retraction. Any small avulsed osseous fragments need to be excised. A single or double #5 nonabsorbable suture is inserted through the tendon using the Krackow whipstitch technique. The mobilization and reduction of the tendon are then assessed. Extended release of the triceps muscle from the posterior aspect of the humerus and from the intermuscular septa and subcutaneous tissue is required in chronic cases when there is a marked degree of tendon retraction; in such cases, the ulnar and radial nerves are decompressed. Debridement of the olecranon footprint with a high-speed burr is followed by the drilling of cruciate 2mm holes, starting at the footprint site and exiting the proximal ulna distal to the olecranon region. The nonabsorbable sutures are then passed through the cruciate holes and the tendon is reattached to the olecranon by means of suture with the elbow in extension. The stability of the reattachment may be evaluated intraoperatively by moving the elbow in extension-flexion. Primary repair in chronic cases should aim to provide flexion to 45°. The wound is then irrigated and closed in layers. One or two subcutaneous drains are applied for 24–48 h. Finally, the arm is immobilized in 45° extension. The main steps of primary repair are shown in Fig. 28.6.

28.12 Results and Complications in Primary Repair

The outcomes of treatment of the triceps ruptures are satisfactory in most cases (Table 28.1) (Mair et al. 2004; Harris et al. 2004; Sherman et al. 1984; Singh and Pooley 2002; Lempainen et al. 2011; Aso and Torisu 1984; Sollender et al. 1998). The lack of reports that contain detailed quantitative data, such as an isokinetic evaluation or subjective and objective outcomes based on standardized functional scores, hampers any attempt to conduct a retrospective clinical comparison and review of such reports. Indeed, range of motion and the clinical evaluation of muscle strength are the only parameters assessed in the majority of these studies. Sollender et al., who treated four weight lifters with a complete rupture of the triceps tendon insertion surgically, reported that all four patients had fully recovered strength and ROM at 7 years of follow-up (Sollender et al. 1998). The only complication they reported was a re-rupture of the triceps tendon during early aggressive weight lifting only 6 weeks after surgery; reoperation on that patient was followed by a satisfactory final outcome. Mair et al. surgically treated 11 football players with complete tears of the triceps tendon; by the final follow-up examination (average 3 years), all 11 patients had regained full range of motion, with none complaining of residual pain or displaying weakness (Mair et al. 2004). In that study, a revision was required for a re-rupture 6 weeks after surgery in one patient, while another decided to retire from professional sports activity following surgery. When Singh and Pooley performed surgery on a professional ice hockey player with an intramuscular triceps rupture, they reported no complications and the player

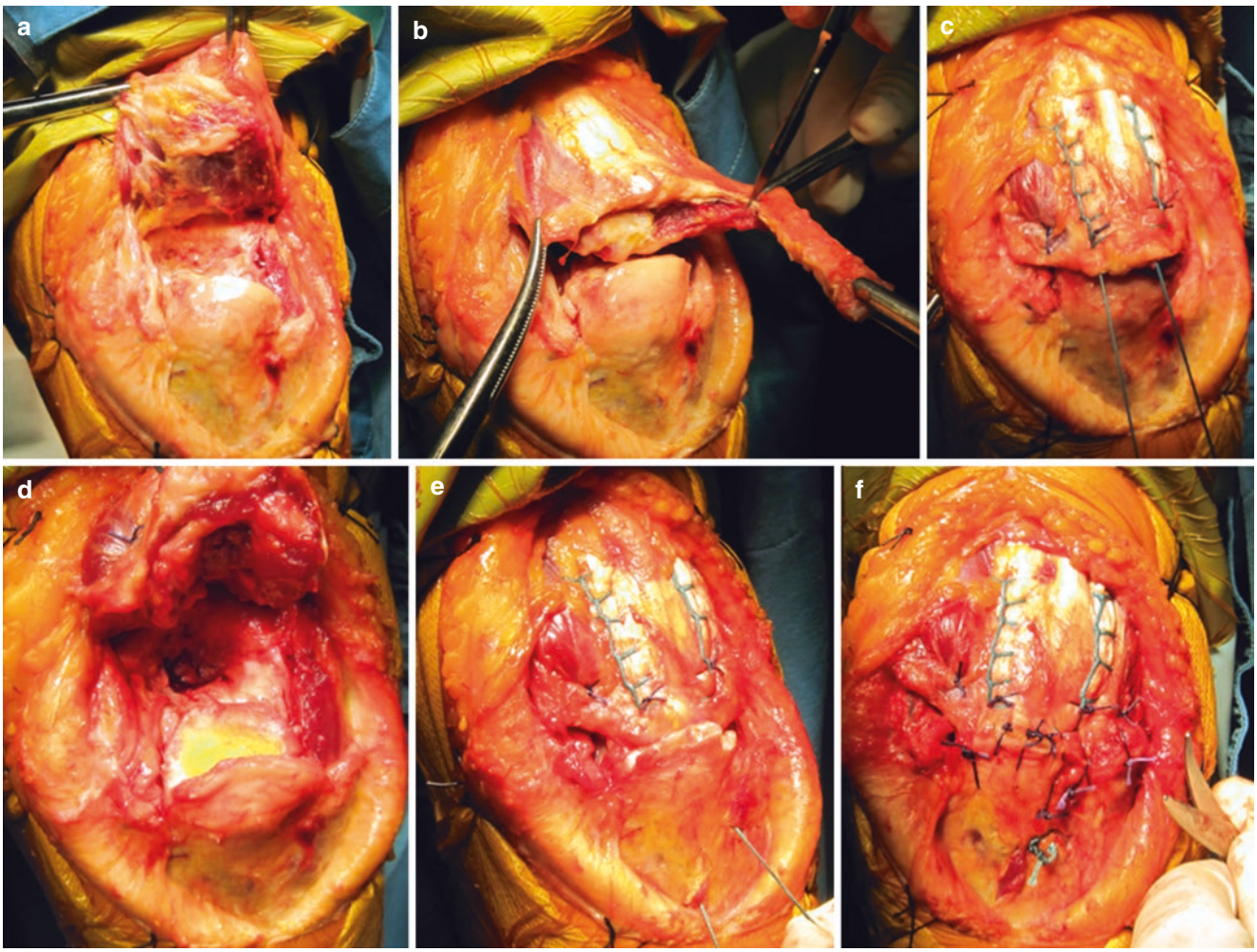


Fig. 28.6 Intraoperative photographs showing the main surgical steps of primary distal triceps tendon reinsertion. (**a**) The ruptured tendon is exposed and the tendon tear is classified: in this case, the lesion involves the superficial and deep layer of the triceps tendon. (**b**) The stump of the avulsed tendon is debrided back to normal-appearing tendon. (**c**) A double Krakow suture is performed, and (**d**) the olecranon footprint is decorticated with a high-speed burr. (**e**) Two cruciate drill holes across the olecranon footprint and exiting the proximal ulna are made, and subsequently the sutures are passed through the drill holes. (**f**) With the elbow in extension, the sutures are tied, and additional reinforcement sutures are performed

returned to sports activity 6 months after surgery (Singh and Pooley 2002). Lempainen et al. surgically treated nine athletes with triceps tears who were involved in power sports requiring heavy weight training: six had myotendinous tears, while three had tendon avulsions (Lempainen et al. 2011). The results were excellent in four, good in four and fair in one at a mean follow-up of 5 years, with all the athletes returning to sports activity after 4–6 months. The triceps muscle in the patient with the fair outcome remained very thin and weak. Few papers studied the results of surgical treatment of triceps tendon ruptures in the general population. Neumann et al. and Kose et al. recently analyzed 8 and 7 patients, respectively, reporting satisfactory results in all the patients; the only major complication was one early traumatic re-rupture of the tendon due to the pull-out of anchors (Neumann et al. 2015; Kose et al. 2015). In general, re-ruptures represent the most common complication following primary repair of the triceps tendon in the literature, with previous studies reporting this event in up to 25% of patients, most of whom are professional sportspeople or subjects with high demands (Sollender et al. 1998; Mair et al. 2004).

In studies conducted on a general population, re-ruptures occurred apparently in a lower percentage that those observed in professional athletes, showing a re-rupture rate ranging from of 0% to 14% (Sierra et al. 2006; Neumann et al. 2015; Kose et al. 2015).

To sum up, a review of the literature reveals that most of patients resume their normal and sport activity and that surgery after triceps tendon rupture yields good functional results and low complication and re-rupture rates.

Table 28.1 Studies regarding triceps tendon injuries

Authors	Study design	No. elbow (type of lesion)	Treatment	Results (F-Up)	Complications
Inhofe and Moneim 1996	Case report	1 (partial)	Surgery	Complete recovery (3 months)	No
Wagner and Cooney 1997	Case report	1 (complete)	Surgery (reconstruction with augmentation)	Complete recovery (3 years)	No
Sollender 1998	Case series	4	Surgery	75% Complete recovery (6, 7 years)	1 Re-rupture at 6 weeks
Duchow 2000	Case report	1 (complete)	Surgery	Complete recovery (3 months)	No
Singh and Pooley 2002	Case report	1 (intramuscular rupture)	Surgery	Complete recovery (6 months)	No
Pina 2002	Case report	1 (complete)	Surgery	Complete recovery (12 months)	No
Sanchez-Sotelo and Morrey 2003	Case series	2 (complete)	Surgery (reconstruction with augmentation)	Complete recovery (2 years)	No
Weistroffer 2003	Case report	1 (complete)	Surgery (reconstruction with augmentation)	Complete recovery (2 years)	No
van Riet 2003	Case series	14 (9 partial–5 complete)	Surgery	Complete recovery (93 months)	3 Required second primary surgery for re-rupture
Mair 2004	Case series	21 (10 partial–11 complete)	Partial: conservative	Partial: 60% healed without symptoms (3 years)	Partial: 1 complete rupture; 3 required surgery for symptoms
			Complete: surgery	Complete: 72% full active ROM, no symptoms (3 years)	Complete: 1 re-rupture at 7 weeks, 1 re-rupture at 6 weeks
Harris 2004	Case report	2 partial (bilateral)	Conservative	Normal function (41 weeks)	No
Tsourvakas 2004	Case report	2 complete (bilateral)	Surgery	Complete recovery (3 months)	No
Sharma 2005	Case report	1 (complete)	Surgery	Complete recovery (9 months)	No
Weng 2006	Case report	1 (partial)	Surgery	Complete recovery (3 months)	No
Sierra 2006	Case series	16 (3 partial–13 complete)	Partial: conservative	Partial: complete recovery	Partial: no
			Complete: 2 conservative 11 surgery	Complete: complete recovery (26 months)	Complete: rerupture, ulnar neuropathy, painful snapping
Tatebe 2007	Case series	2 (partial)	Surgery	Complete recovery (17 months)	No
Wolf 2008	Case report	1 (partial)	Surgery (reconstruction with augmentation)	Complete recovery (6 months)	No
McCulloch 2008	Case report	1 (complete)	Surgery	Complete recovery (6 months)	No
Athwal 2009	Case series	2 (partial)	Surgery	Complete recovery (2 years)	No
Daglar 2009	Case report	1 (complete)	Surgery	Complete recovery (10 months)	No
Chan 2009	Case report	1 complete	Surgery	Complete recovery (3 months)	No
Gupta and Murthi 2010	Case report	1 (complete)	Surgery	Complete recovery (3 years)	No
Lempainen 2011	Case series	10 (6 myotendinous 3 avulsion from olecranon 1 avulsion from scapula)	Surgery	90% Good-excellent (5 years)	No
Khiami 2012	Case report	1	Surgery	Complete recovery (4 months)	No
Bava 2012	Case series	5	Surgery	Complete recovery (32 months)	No
Kokkalis 2013	Case series	10 (8 avulsion from olecranon 3 musculotendinous junction)	Surgery	Complete recovery (21 months)	No
Neumann 2015	Case series	7	Surgery	Complete recovery (12 months)	1 Required second primary surgery for re-rupture
Kose 2015	Case series	8	Surgery	Complete recovery (19 months)	No
Tarallo 2015	Case report	1 (complete)	Surgery	Complete recovery (30 days)	No

28.13 Salvage Procedures in Chronic Tendon Insufficiency

The English literature contains reports of athletes treated for chronic tendon insufficiency by means of salvage procedures.

Chronic ruptures, i.e., injuries that are at least 6 weeks old, are usually due to a delay either in the diagnosis or between the occurrence of injury and request for treatment (Yeh et al. 2010b). The choice of treatment for chronic triceps lesions is usually dependent on the quality of tissue and the degree of tendinous retraction. If the tendon quality is good and retraction is minimal, it is possible to perform delayed primary repair as described above.

Several reconstructive procedures have instead been described in patients with poor tendon quality, in whom there may be a marked gap between the stump of the retracted tendon and the footprint after a long-lasting release (Weistroffer et al. 2003; Sanchez-Sotelo and Morrey 2002; Wagner and Cooney 1997; Sai et al. 2004; Dos Remedios et al. 2007). In 1984, Clayton performed a triceps fascial turndown in a case report (inverted V-Y technique) and obtained a good outcome. Farrar and Lippert used a forearm fascial flap to repair the tendon (Farrar and Lippert 1981). It should however be borne in mind that these techniques are neither reliable nor reproducible if there is a marked degree of soft tissue deficiency at the insertion site.

The anconeus slide, or anconeus rotation flap technique, described by Sanchez-Sotelo and Morrey, can be used for minor defects and when the anconeus is intact (Fig. 28.7a) (Sanchez-Sotelo and Morrey 2002). The muscle is mobilized from its insertions to the lateral triceps; the sleeve of the extensor musculature is attached distally and medially so as to fully cover the site of the triceps attachment with the elbow in 30° flexion. The four patients treated by the authors

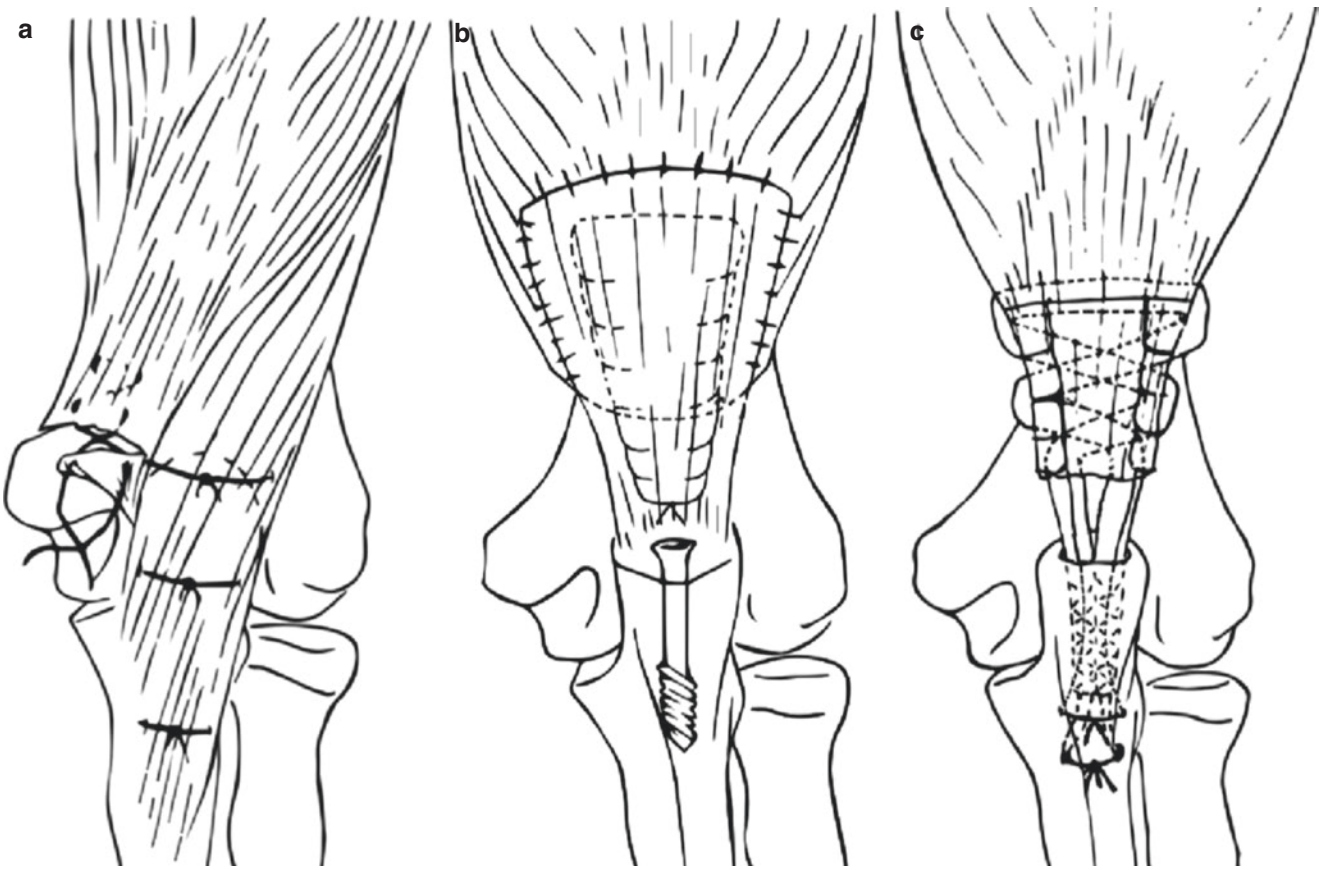


Fig. 28.7 (**a**) The "anconeus slide" technique. The anconeus muscle is elevated from the ulna and the humerus insertions in continuity with the lateral triceps and oriented over the tip of the olecranon and reattached to the olecranon in 30° of flexion. The central and medial portion of the triceps were sutured to the extensor mechanism to reinforce it. (**b**) Reconstruction with Achilles tendon allograft. A cancellous screw is used to fix the distal calcaneus bone graft to the osteotomy of the proximal olecranon. The remainder of the reconstruction consists of the reattaching the Achilles tendon to the triceps tendon and muscle using a #2 or #5 high-strength running sutures. Finally other single or cross-stitch sutures are used to attach the aponeurosis of the Achilles tendon to the triceps. (**c**) Hamstring autograft reconstruction. The autograft semitendinosus tendon (or two tendons) is woven in a Bunnell fashion through the remaining proximal triceps tendon. A transosseous tunnel is then drilled through the proximal olecranon, and the two free ends of the hamstring tendon are then passed through the transosseous tunnel and fixed to the proximal ulna

regained their full ROM and strength, with no pain being reported during activity, at a mean postoperative follow-up of 49 months. The results were similar when the same technique was used by Van Riet et al. (2003).

Cases with marked soft tissue deficiency or a devitalized anconeus may be treated by means of other techniques, such as tendon augmentations. In 2002, Sanchez-Sotelo and Morrey used an Achilles tendon and calcaneus osseous fragment allograft to reconstruct the tendon (Fig. 28.7b) (Sanchez-Sotelo and Morrey 2002). This operation entails fastening the distal calcaneus block into a V-shaped osteotomy of the proximal olecranon using a cancellous screw. The proximal Achilles tendon allograft can then be stitched using nonabsorbable suture to the triceps muscle and tendon with the elbow in 30° flexion. The results reported by the authors were satisfactory after a mean follow-up of 38 months.

Other authors have described a hamstring autograft reconstruction to repair challenging cases (Fig. 28.7c) (Kaempffe and Lerner 1996; Wolf et al. 2008). When this technique is used, the semitendinosus tendon autograft is woven in a Bunnell fashion through the remaining proximal triceps tendon. A transosseous tunnel, centered between the articular surface and the posterior cortex, is then drilled through the proximal olecranon, 1 cm distal from its tip. The two free ends of the hamstring tendon are passed through the transosseous tunnel in a retrograde fashion, with the elbow being placed in full extension as the tendon stump is reduced to the olecranon. This technique has yielded satisfactory results (Weistroffer et al. 2003; Wolf et al. 2008), though full strength is recovered more slowly than when an Achilles tendon allograft is performed. Indeed, some authors believe that the Achilles tendon allograft technique provides better long-term results than the hamstring autograft, particularly in view of possible hamstring weakness and atrophy after graft removal (Weistroffer et al. 2003; Sanchez-Sotelo and Morrey 2002; Wolf et al. 2008). The Achilles tendon allograft technique may thus be more indicated when treating athletes.

28.14 Postoperative Care

There are varying reports on postoperative rehabilitation in the literature. Some authors propose similar postoperative treatment and rehabilitation protocols in both nonathletes and professional athletes.

Blackmore et al. reviewed the literature on this topic, providing a detailed report of postoperative care (Blackmore et al. 2006). They recommended that the elbow be immobilized in a cast in 30° flexion for 2 weeks following surgery, and immobilization in a hinged elbow brace in 45°, 60°, and 90° flexion for the subsequent 3 weeks. Full active flexion and extension can be performed 6 weeks after surgery, whereas extension strengthening is started at 12 weeks. Passive full flexion, if required, is allowed at 8 weeks. Finally, unrestricted activity is allowed after the fifth month.

The sports clinician is faced with the additional question of whether and, if so, when the patient can return to sport. Several weeks without any sports activity may be adequate for athletes with a partial triceps tendon injury. In one study, nine professional football players returned to full-contact sports activity with a brace support and completed their seasons after a mean recovery period of 5 weeks (Mair et al. 2004). Similarly, a male high-level bodybuilder with bilateral partial triceps tendon tears returned to his normal weight lifting regimen without a brace support after a 4-week recovery period (Harris et al. 2004). Athletes should be aware that some degree of pain and weakness may persist despite a period of rest (Mair et al. 2004; Harris et al. 2004). Moreover, an immediate return to athletic activities may increase the risk of a complete rupture or chronic extensor dysfunction (Mair et al. 2004; Duchow et al. 2000; Weng and Wang 2006; Sollender et al. 1998). In the largest case series of professional sports players described in the literature, Mair et al. reported that one patient returned to full-contact professional football after 7 weeks without sustaining a re-rupture, while another ten patients required a longer rehabilitation period (Mair et al. 2004).

In conclusion, a mean rehabilitation period of between 4 and 6 months is recommended for professional sports players and heavy activities because an earlier return may expose the patients to a risk of re-rupture (Van Riet et al. 2003; Singh and Pooley 2002; Sollender et al. 1998). The length of postoperative care may also vary from case to case depending on the tension and quality of the tendon repair, on other concomitant injuries, as well as on the patient's medical history; this is particularly true of patients who have undergone reconstructive procedures and in whom the recovery process is consequently longer.

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Snapping Triceps

29

Giovanni Ciaramella, Marco Saporito, Francesco Fauci, and Giuseppe Porcellini

29.1 Introduction

Snapping of the medial head of the triceps, first described by Rolfsen back in 1970, has scarcely been described in the literature most likely because its clinical entity has long been unknown and underestimated. Recurrent snapping of the triceps is usually accompanied by ulnar nerve dislocation (Fig. 29.1). Patients affected by this condition may manifest a wide array of clinical features ranging from a complete absence of symptoms to pain and ulnar nerve neuropathy.

29.2 Definition of Snapping Triceps

Snapping triceps is a dynamic phenomenon in which a part of the distal triceps is dislocated over the medial epicondyle when the elbow is flexed.

29.3 Epidemiology

To date, not much is known about the epidemiology of snapping triceps, for its low incidence and prevalence have never been quantified. What is known is that it generally affects people between the ages of 10 and 53 years (Spinner and Goldner 1998; Vanhees et al. 2010; Watts et al. 2009), with a higher incidence among males (Spinner and Goldner 1998; Vanhees et al. 2010; Watts et al. 2009). Occasionally, it may affect both arms. The major risk factors associated with this condition arise either from work or sport activities requiring repetitive flexion-extension against resistance of the elbow (Spinner and Goldner 1998; Vanhees et al. 2010; Watts et al. 2009), from posttraumatic cubitus varus deformities or from ulnar nerve anterior transposition (Spinner and Gabel 2001).



Fig. 29.1 Snapping of the triceps and the ulnar nerve over the medial epicondyle

29.4 Differential Diagnosis

Snapping triceps is difficult to diagnose because many of its symptoms are similar to those of other conditions. Among these are ulnar nerve compression, ulnar nerve instability,

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Table 29.1 Inta-articular and extra-articular cause of Snapping Triceps

	Extra-articular cause	
Intra-articular cause	Medial	Lateral
Radiohumeral menisci (Kang and Kim 2010)	Ulnar nerve instability	Snapping annular ligament over radial head (Huang et al. 2005; Aoki et al. 2003; Chai et al. 2015)
Synovial plica (Clarcke 1988; Steinert et al. 2010) Loose body	Snapping brachialis muscle (Rudy and Armstrong 2007) Snapping triceps (medial head)	Snapping triceps (lateral head) (Spinner et al. 1999) Posterolateral elbow rotator instability
Inflammatory process		

medial epicondylitis, little league elbow syndrome, and distal ulnar rupture. Generally, a snapping elbow can be due to intra-articular or extra-articular causes (Chan and Wu 2011) (Table 29.1). Snapping triceps, which is a rare cause, belongs to the latter group.

29.5 Etiopathogenesis

Although the etiopathogenetic mechanisms underlying snapping triceps and its natural history are still unknown, several factors may be linked to its development, including anatomical, occupational, genetic, and iatrogenic factors. Anatomical factors, which are the ones most widely studied, may include alterations in the anatomy of triceps or in the bones of the elbow. These alterations may be either congenital or acquired. As the name suggests, the triceps muscle is divided into three sections: the long, medial, and lateral heads. A fourth medial head has also been identified but has rarely been described (Fabrizio and Clemente 1997). The triceps intersects both with tendons and muscles. More specifically, it inserts with the tendinous terminal portion on the olecranon (referred to as proper part) and with the muscle-tendinous extension (referred to as second part). The latter inserts into four different areas: (1) medially, into the posterior crest of the ulna; (2) laterally, into the fascia of the origin of the extensor carpi ulnaris; (3) distally, into the antibrachial fascia; and (4) deeply, into the anconeus insertion (Gabel et al. 1998). The portion of the triceps near the epitrochlea is thinner and wider compared to the part that inserts on the olecranon (Gabel et al. 1998). In particular, when the elbow is flexed, the triceps muscle flattens out owing to the ensuing compression on the distal humerus. This event, by reducing the distance of the triceps from the epitrocleis (Spinner et al. 2001), constitutes a major predisposing factor to snapping. Generally, the ulnar nerve is anteriorly and medially dislocated from the medial head by 7.5 mm (Spinner and Goldner 1998). Thus, snapping triceps could be due to several factors including a fourth medial head, a prominent or hypertrophic portion of the medial triceps, an accessory tendon, an anomalous insertion, or a short distance between the medial epicondyle and the medial edge of the triceps (Spinner and Goldner 1998; Vanhees et al. 2010; Watts et al. 2009; Chan and Wu 2011; Fabrizio and Clemente 1997; Spinner et al. 2001; Dellon 1986; Reis 1980). In this regard, studies report that such distance is shorter when the transition between the muscle and the tendon of the medial triceps is localized distally (Spinner and Goldner 1998; Vanhees et al. 2010). Boon et al. initially hypothesized that in patients with snapping triceps, there might be an anomalous activation of the firing pattern of the triceps heads (Boon et al. 2007). However, in their electromyographic investigation, they found no significant differences between subjects and controls.

Bone alterations can also contribute to snapping triceps, in particular those altering the normal load-bearing lines of the triceps. Spinner et al., using 3D mathematical, plastic, and cadaver models, demonstrated that a congenital or posttraumatic angular misalignment in varus of the distal humerus can cause a significant snapping of the triceps medially which can eventually dislocate above the medial epicondyle during flexion. Another example is in patients affected by developmental cubitus varus. In these cases, the force vector of the triceps, which is displaced medially, causes a medial elongation of the olecranon which then evolves into the most prominent medial structure. Palpation of the medial epicondyle oftentimes becomes difficult and can be mistaken for the olecranon itself. Such deformity can actually displace the insertion point of the triceps medially (Spinner et al. 2001). Finally, other potential bone alterations that can lead to the snapping of the triceps muscle are hypoplasia of the medial epicondyle and a shallow cubital tunnel with an insufficient retinaculum (Vanhees et al. 2010; Chan and Wu 2011; Spinner et al. 2001).

Regarding occupational causes, snapping triceps most commonly affects manual workers or athletes (Spinner and Goldner 1998; Vanhees et al. 2010; Watts et al. 2009; Chan and Wu 2011; Spinner et al. 2001). In particular, the major work-related risk factors include overhead pitching, weightlifting, push-ups, and rowing. All of these activities require repetitive flexion of the elbow well above 90° with an extension against resistance. For instance, when pitching a ball, valgus stress increases during cocking and early acceleration. In the long run, these movements may result in acquired triceps hypertrophy.

Besides anatomical deformities and occupational factors, iatrogenic causes have also been shown to play a role. Spinner and Gabel (2001), on the basis of their direct

experience and previous literature (Haws and Brown 1995; Minami et al. 1999), have suggested that snapping triceps may result from ulnar nerve transposition. In brief, they have indicated that the resection of the medial intermuscular septum (MIS) and of the brachial fascia causes the triceps to dislocate over the medial epicondyle during flexion. This is why an intraoperative assessment of the stability of the medial triceps during flexion is paramount to prevent postoperative complications. Elbow stability can be classified into three main types: Type 1, stable; Type 2, subluxation in flexion; and Type 3, luxation above medial epicondyle in flexion. In the event of a Type 2/3 subluxation, resection or lateral transposition of the affected muscle is recommended.

Finally, whether people may be genetically susceptible to snapping triceps has not yet been fully established. Although some authors have described a case in which members of a three-generation family with Waardenburg phenotype (Spinner et al. 1997) were affected by this condition, more genetic analyses are definitely warranted.

29.6 Clinical Evaluation

The clinical picture of snapping triceps is extremely variable (Spinner and Goldner 1998; Vanhees et al. 2010). Commonly, snapping of the medial triceps over the medial epicondyle is very subtle and can be detected through careful palpation. Only occasionally can the snapping be actually heard or seen (Spinner and Goldner 1998). Snapping occurs when the elbow passes from an extended to a flexed position. Some patients may be asymptomatic and learn out about their condition only accidentally. Others, instead, experience pain localized to the medial or posteromedial side of the elbow. Medial elbow pain may stem from neuropathy or from an inflammatory reaction of the triceps tendon or of the bursa near the medial epicondyle (Spinner and Goldner 1998; Vanhees et al. 2010). Finally, others may manifest ulnar nerve neuropathy or medial pain accompanied by neuropathy (Spinner and Goldner 1998; Vanhees et al. 2010; Watts et al. 2009; Chan and Wu 2011). Neuropathic symptoms can be due to subluxation of the nerve and to chronic friction and inflammation ensuing thereafter or to compression by the triceps.

All such symptoms may arise or even worsen during some sport activities including weightlifting, push-ups, or breaststroke swimming (Spinner and Goldner 1998; Vanhees et al. 2010; Watts et al. 2009; Chan and Wu 2011). Physical examination should entail a thorough assessment of the elbow through active and passive movements of flexion and extension, as well as against resistance, during eccentric contraction of the triceps. Simultaneously, the examiner should palpate the ulnar nerve. Furthermore, a full extension of the triceps muscle can be obtained by having the patient raise his/her arm above his/her head, a position that, among other things, allows the examiner to have a better view of the back of the elbow. In practice, induction of passive flexion can induce a double snapping: one elicited by the ulnar nerve when the elbow is flexed from about 70° to 90° and the other elicited by the triceps when the elbow is flexed at about 115° (Fig. 29.2) (Spinner and Goldner 1998; Vanhees et al. 2010; Watts et al. 2009;

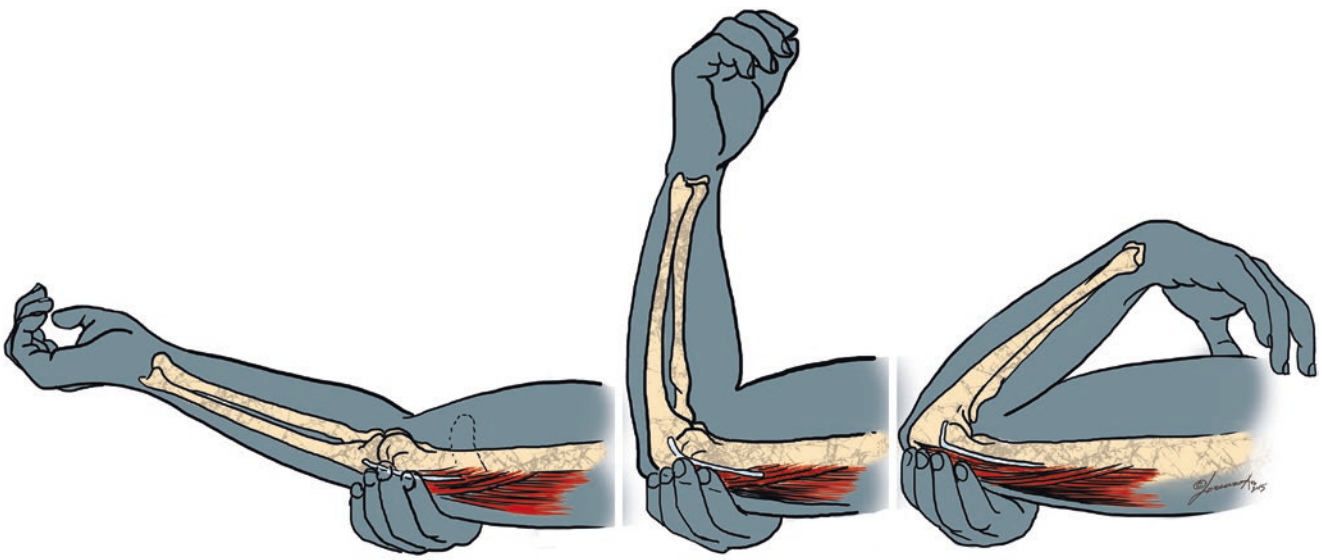


Fig. 29.2 Induction of passive flexion can induce a double snapping: one elicited by the ulnar nerve when the elbow is flexed from about 70° to 90° and the other elicited by the triceps when the elbow is flexed at about

Chan and Wu 2011; Spinner et al. 2001). Dislocation can also be induced through active flexion but at minor degrees of flexion. Overall, although snapping triceps is generally easy to diagnosis, it may sometimes be very challenging to detect and to distinguish from other similar conditions including ulnar nerve dislocation. To complicate the diagnostic scenario, symptoms may occur intermittently, i.e., only during physical activity (Spinner and Goldner 1998; Spinner et al. 2001).

29.7 Radiological Evaluation

Magnetic resonance imaging (MRI) (Vanhees et al. 2010) and dynamic ultrasound imaging (Spinner and Goldner 2002; Spinner et al. 1996; Yiannakopoulos 2002; Lasecki et al. 2014; Jacobson et al. 2001) can definitely be of diagnostic support. In brief, MRIs should be performed with the elbow in flexion and in extension. It should be noted that muscle dislocation becomes visible only when the elbow is flexed above 100°. As opposed to physical examinations, imaging techniques can clearly reveal the complex relationships between the different anatomical structures and are not operator-dependent (Spinner and Goldner 2002; Spinner et al. 1996). For instance, ultrasound sonography (US) is a fast and cheap technique that can provide a dynamic evaluation of the elbow by capturing real-time images. Furthermore, they offer a number of advantages that outweigh the disadvantage of being, to a certain extent, operator-dependent. Whereas Jacobsen et al. (Lasecki et al. 2014) have reported their personal technical procedure, Lasecki et al. (Yiannakopoulos 2002) have described a clinical case in which MRI, US, and elastosonography were all used as diagnostic tools. They found that the ulnar nerve trunk and the additional band of the medial triceps were more rigid than those of the healthy contralateral arm. Furthermore, MRI revealed a fatty/mucoid degeneration of the accessory muscle band despite the absence of hyperemia or inflammation. Unfortunately, because these findings were not interpreted by these authors, further investigation is warranted. Lastly, another alternative diagnostic procedure is electroneurography. However, this technique is not always as reliable as the previous ones. Indeed, owing to the dynamic nature of ulnar nerve compression, it often yields false negative results and can rarely detect signs of ulnar neuropathy (Vanhees et al. 2010).

29.8 Therapeutic Management

To date, there is still a general dearth of literature on the ideal therapeutic management for snapping triceps. In most cases, surgeons choose conservative treatment as their first treatment option, and only, secondarily, when all other options have failed, do they resort to surgery. In particular, such approach entails a combination of complete withdrawal from physical activities entailing repetitive flexion-extension activities of the elbow (push-ups, pull-ups, weightlifting, overhead/overhand throwing, breaststroke swimming), medications (NSAIDs), and elbow splinting in 70° flexion. Local infiltrations of corticosteroids, or their derivatives, are not advisable. Eventually, such treatment protocol leads to improvement or resolution of symptoms (Vanhees et al. 2010; Spinner and Goldner 2002). However, if symptoms do not improve after 3–6 months, surgery is generally prescribed.

The rationale behind surgical treatment is to remove or reduce elements luxating the triceps and the ulnar nerve and to decompress or stabilize the ulnar nerve. The snapping triceps can be corrected by resecting or transposing the luxated part of the muscle. During surgery, it is not easy for surgeons to evaluate the amount of triceps to remove. The difficulty lies in the fact that muscle activation under anesthesia is impossible, thereby making it hard for surgeons to visualize the extent of the snapping. Resection is recommended when only a small part of the triceps is affected. One reason is that, although resection is a rather simple procedure and facilitates a short recovery period, resection of a large portion of the muscle could impair muscle function. Accordingly, lateral transposition of the luxated portion is highly recommendable in these cases (Fig. 29.3a–d).

One major advantage of lateral muscle transpositions is that it does not luxate the ulnar nerve, and, even when it does, a simple decompression of the nerve is sufficient to repair it. However, when the luxation persists, anterior transposition is required. Ideally, at the end of the surgical procedure, the elbow should be painstakingly examined. Unfortunately, as mentioned above, such assessment is more easily said than done owing to the impossibility of engendering a muscle contraction under anesthesia. After surgery, the elbow should be immobilized at 70° of flexion for about 3–5 days. Subsequently, the patient can gradually engage in passive mobilization based on his or her

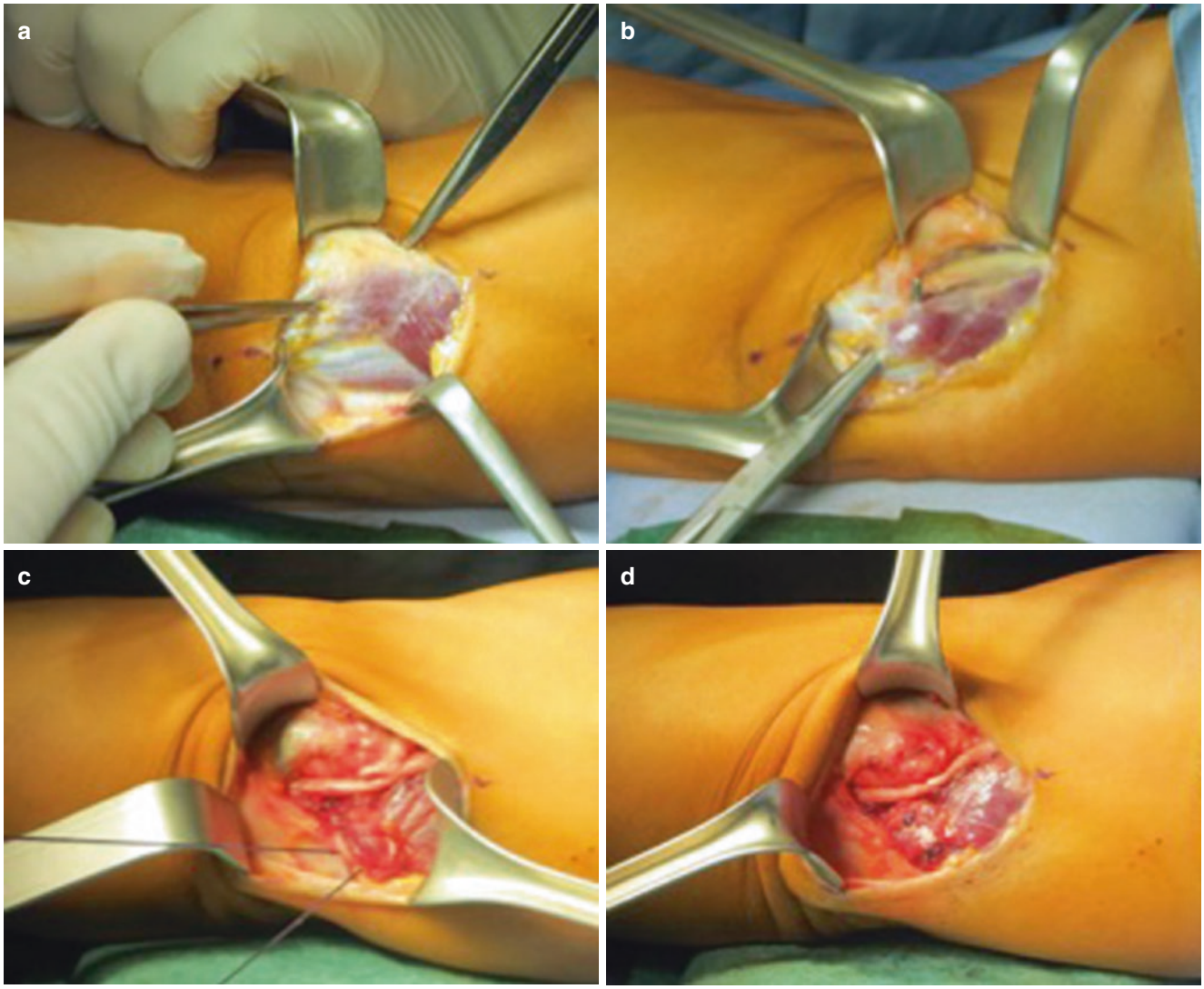


Fig. 29.3 Case report: 18-year-old professional tennis player, with snapping, medial elbow pain, and symptoms of neuropathy of the ulnar nerve for more than six months. Medial anomalous insertion of the medial head of the triceps with muscle hypertrophy (**a**, **b**). Detachment of the tendon medial portion and its reinsertion (**c**, **d**)

tolerance. In case of transposition, active mobilization can begin in 5 weeks. Lastly, corrective osteotomy is prescribed when the condition is due to cubitus varus.

29.9 Brief Overview of Surgical Outcomes

So far, very few data have been reported on the surgical outcomes for the treatment of snapping triceps. In most cases, they consist of brief case series (Spinner and Goldner 1998; Spinner et al. 2000) or case reports (Rolfsen 1970; Watts et al. 2009; Reis 1980; Haws and Brown 1995; Minami et al. 1999; Dreyfuss and Kessler 1978). One case series is that by Spinner and Goldner (1998). They evaluated 22 elbows of 17 patients with snapping triceps. Five were completely asymptomatic, two had snapping without pain, five had snapping and medial pain, three had ulnar nerve neuropathy, and seven had snapping and neuropathic symptoms. Out of these 17 patients, seven underwent surgery. In brief, six underwent resection or muscle transposition,

together with ulnar nerve transposition, and one underwent humeral valgus osteotomy. Remarkably, after a mean follow-up of 4.5 years (range between 2.5 and 8 years), all patients were symptom-free.

In another case series by Spinner et al. (2000), the authors reported on 15 patients who sustained a painful snapping of the elbow after undergoing ulnar nerve transposition. In seven of these patients, the condition was accompanied by neuropathic symptoms, most likely for the missed diagnosed. Therefore, nine patients underwent resection or transposition of the medial portion of the triceps. As in the cases described above, healing occurred in all patients.

Similar promising results have been reported in several case reports. Rolfsen (1970) published a case report of a patient who was successfully treated after undergoing resection of the medial aspect of the tendon. Likewise, Dreyfuss and Kessler (1978) described two cases in which patients were also surgically treated with tendon transposition. After 6 months, snapping reoccurred only in one of the two patients though without ulnar nerve neuropathy. Finally, Watts et al. (2009) described three clinical studies. Two were treated with transposition, and one, who was a 14-year-old boy hoping to become a rugby player, was treated with division of the tendon. As for the other cases, all patients had complete resolution of their symptoms.

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Elbow Stiffness

30

Enrico Guerra, Alessandro Marinelli, and Marco Rotini

30.1 Introduction

The primary function of the elbow is to position and stabilize the hand in space. It has been estimated that to obtain this, the required physiologic arc of movement is about 0–145° for extension and flexion, respectively, and of 70–85° for pronation and supination (Palastanga et al. 2006). Morrey et al. (1981) stated that, to perform the basic activity of daily living, a minimum arc of movement of 30–130° in extension and flexion and of 50–50° in pronation and supination is enough. A stiff elbow has been defined by Sojbjerg as one with a loss of extension greater than 30° and less than 120° of flexion (Sojbjerg 1996). From these data we must put our attention to the fact that a loss of terminal extension is less disabling than a loss of the same degree of terminal flexion: this will be important when we will deal with the rehabilitation program.

It's important to underline that elbow stiffness is poorly tolerated because of the lack of compensatory motions in adjacent joints. Therefore, it should not come as a surprise if some patients with particular occupational or recreational requests come to our attention requiring help and treatment even with articular limitation we judge of small amplitude.

It is very difficult to estimate the real incidence of this problem since, unfortunately, the elbow joint is prone to stiffness following a multitude of traumatic (including burns, head injury, and elbow surgery) and atraumatic (osteoarthritis and inflammatory joint disease, metabolic disease like in hemophiliacs, and congenital like arthrogryposis) etiologies.

Certainly, the most common cause among those aforementioned is elbow trauma. Not only trauma can directly alter the geometry of the joint, but it can also induce a number of secondary effects on the soft tissues around the elbow itself. Both situations can be further complicated by the formation of heterotopic ossification. Heterotopic ossifications commonly occur about the elbow in response to tissue trauma; these act as a physical block to elbow motion and might also create a synostosis between the radius and ulna, preventing forearm pronation/supination (Nandi et al. 2009).

Soft tissue contracture leads to stiffness by physically restricting elbow motion. These soft tissue changes typically occur with the bony pathology mentioned above because these situations are often followed by contracture of the articular capsule, collateral ligaments, and muscles (Sojbjerg et al. 2002).

When the skin covering the elbow is no longer supple following a burn, motion could be again compromised (Jupiter et al. 2003). But above all, one of the biggest changers trauma can induce in the joint capsule is represented by an increased number of myofibroblasts (i.e., fibroblasts with contractile ability) in its thickness. It has indeed demonstrated a significant correlation between joint range of motion and myofibroblast numbers, percentage of myofibroblast to total cells, and α-SMA (i.e., a contractile smooth muscle protein expressed by myofibroblast and therefore a myofibroblast marker) protein levels in the capsules of patients with post-traumatic joint contractures (Hildebrand et al. 2004).

Moreover, even if myofibroblastic proliferation occurs throughout the entire joint capsule, there seems to be a selectively greater increase of their number in the anterior part of the capsule compared to the posterior part. This is one of the reasons why most of elbow contractures occur in a flexed position (Germscheid and Hildebrand 2006).

In the same way, the anterior part of the post-traumatic joint capsule is an environment with high matrix turnover rates, which makes it much thicker than physiological (from 0.5 mm to 8 mm) with an extensive disorganization of the collagen fiber bundle arrangement. This is another reason explaining why the greater part of post-traumatic elbow contractures is in flexion (Hildebrand et al. 2005).

According to Morrey (2005), the high degree of congruity and complexity of the articular joint and the susceptibility of

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the tissues (particularly the capsule) to react to trauma are the two basic anatomic features that underlie the elbow loss of motion, but they're not the only ones.

Indeed, another predisposing factor to elbow stiffness is the brachialis muscle. This muscle is broad and lies directly on the capsule as it crosses the elbow joint. It is highly vascularized, has no tendinous portion at this point, and, therefore, bleeds in response to trauma. Hematoma has been implicated as an inciting cause of heterotopic ossifications and subsequent capsular contracture (Husband and Hastings 1990). Moreover, the medial and lateral collateral ligaments are often injured in elbow fractures, dislocations, or even less traumatic injuries and have a propensity toward calcification (Weiss and Sachar 1994).

30.2 Clinical Evaluation

Patient coming to our attention with a stiff elbow needs to be carefully evaluated with an appropriate history and physical examination complemented by imaging studies.

During the medical visit, it is essential to understand the functional impact of the contracture on patient's work or recreational activities, the way patient really lives this disability, and, above all, the compliance with rehabilitation or postoperative therapy. Everything must be investigated, with regard to both stiffness characteristics (onset, duration, clinical trend, prior treatments, etc.) and patient general health state (presence of comorbid conditions) and lifestyle in order to determine the level of demand that will be placed on the elbow. Usually the nature of the problem becomes clear from the history.

The etiology is usually post-traumatic. In these cases trauma dynamics, the presence of fractures, surgical treatment (approach, hardware presence, etc.), and immobilization time must be painstakingly evaluated.

If stiffness instead developed gradually by the years, we should try to understand if it was preceded by elbow pain, that the patient might have tried to mitigate at the expense of range of motion, with rigidity as a result of soft tissue contracture alone. This is the case of synovitis (rheumatic or neoplastic, mostly benign such as osteoid osteoma).

Differently, when stiffness has slow onset but with mild and sustainable pain, we must look for the cause in elbow cartilage damage and osteoarthritic changes (from loose bodies to osteophytes and intra-articular ossifications). These patients are usually heavy manual workers subject to repetitive mechanical stress which leads to the formation of anterior and posterior osteophytes, with progressive reduction of active and passive range of motion, as well as sportive patients with a history of unacknowledged osteochondritis dissecans or mild medial instability and repeated valgus stress during athletic activity.

If that is the case, the patient seeks our attention only when the range of motion limitation is so pronounced that it affects working or recreational activity; pain is usually minimum and supportable, mostly exacerbated by stretches over the permitted articular range.

Physical examination needs to include a complete evaluation of the entire upper limb involved and comparison with the contralateral. First, we can collect informations from the skin (burns, wounds, etc.). Active and passive elbow range of motion, for both flexion–extension and pronation–supination, should be examined with a goniometer, just as varus–valgus and rotational stability. Also, the quality of the end point is critical: the experienced examiner can often discern between a bony block and an advanced soft tissue contracture (Vardakas et al. 2002).

Motor strength and voluntary control of muscles in the upper limb should be carefully evaluated because an elbow with inadequate motor strength is unlikely to maintain motion after elbow release.

Fundamental is the neurovascular examination with particular attention to the ulnar nerve, which is commonly involved in elbow trauma and may require treatment at the time of surgery (King and Faber 2000).

30.3 Imaging

The first imaging studies to evaluate a stiff elbow should be plain radiographs, including anterior–posterior, lateral, and two oblique views (Nandi et al. 2009).

X-rays provide most of the informations regarding the cause and appropriate management of the contracture. In the event that we need further details, we can take advantage from the CT scan with two- and three-dimensional reconstructions (fundamental in heterotopic ossification study) or MRI if a soft tissue or synovial problem is suspected. Live fluoroscopy can be used to distinguish between a bony block and soft tissue contracture. An EMG could be necessary in cases of ulnar nerve impairment.

30.4 Etiology and Classification

Since the causes of elbow stiffness are so numerous, an etiology-based classification is an obvious first choice. It can be described as following:

- Post-traumatic
- Arthritis
  - Inflammatory
  - OA
  - Dysplasia, etc.

Table 30.1 Elbow stiffness classification (Morrey)

Intrinsic	Extrinsic	Mixed
• Articular incongruence • Cartilage damage • Loose bodies • Osteophytes • Fovea impingement (olecranon, coronoid, and/or radial head)	• Capsular contracture • Muscle/tendon retraction • Ulnar nerve neuropathy • Heterotopic ossification	

- Neurogenic
- Tumor
- Others, etc. (burns, iatrogenic, etc.)

Each one of these disease can affect and reduce the range of motion due to internal and external articular damage.

Traditionally, elbow contractures are classified on the basis of the underlying pathology in extrinsic (e.g., thickening of the ligaments or heterotopic ossification), intrinsic (e.g., osteophyte formation or fracture malunion) and mixed, because since following intrinsic contractures patient may experience secondary contracture of the capsule, ligaments, and muscle of the elbow (Morrey 1990) (Table 30.1).

This is not a merely academic distinction but allows to choose the treatment for that elbow. As an example, it's not possible to obtain motion improvement by passive manual stretching if we are facing an intrinsic stiffness.

Another useful stiffness classification is based on the severity: very severe (≤30°), severe (31–61°), moderate (61–91°), and poor (≥90°).

It's important for the prognosis infact the worse is the stiffness the more difficult is gain the passive motion.

When we suggest the surgery, we have to remember that:

– It's impossible to guarantee the complete recovery also in more simple cases.
– Patients with a poor stiffness have more high expectations and will be less satisfied with a partial joint recovery.

30.5 Conservative Treatment

The stiff elbow is challenging to treat, and thus, its prevention is of paramount importance.

Early identification and treatment of the base pathology, reducing immobilization as much as possible, precise re-education, and control of pain are the main principles to lower the risk of stiffness.

When stiffness already set in, we must find the most appropriate treatment. The conservative treatment is based on functional re-education, physical therapy, and use of splint and passive mobilization. This approach is mostly effective on soft tissue contracture without mechanical sources of stiffness. Actually, in most cases the soft tissue contracture worsens the stiffness caused by intrinsic or extrinsic joint alterations, such as *heterotopic ossification*. For this reason, a 3–6-month period of conservative treatment is still suggested before considering surgical treatment.

It is widely accepted as a severe or moderate post-traumatic stiffness can evolve, respectively, into a moderate or mild stiffness with conservative treatment alone. This can lead to make the stiffness much better tolerated by the patient (who might not wish for surgery anymore) or allow for a better outcome after the surgery if still needed.

The only exception is represented by the ulnar nerve irritation which can compromise the recovery of flexion movement. In the presence of *dysaesthesia or paraesthesia* during flexion manipulation, not regressing with rest and interfering with the re-education, an EMG is strongly suggested together with taking into consideration a neurolysis any time soon. More about this topic can be found in the rehabilitation section of this chapter.

30.6 Surgical Treatment (Open or Arthroscopic)

The surgical treatment for elbow stiffness is needed when the degree of rigidity left from the conservative treatment interferes with work/daily life activities of the patient. Pain and joint lockup during flexion–extension movement are suggestive of surgical indication.

In elbow pathology the diatribe between open and arthroscopic surgery is absent, since both techniques have advantages and disadvantages, often with comparable indications. The surgeon mastering both techniques is most likely to find the most useful and effective approach for each patient based on stiffness type and his own skills.

Arthroscopic techniques are, however, more difficult in cases of severe contracture or when previous surgeries have been undertaken, particularly when there is internal fixation in situ.

During preoperative timing, we must remind to the patient that stiffness, especially within the elbow, tends to recur (due to the new formation of heterotopic ossifications or soft tissue contracture) even when the surgical and rehabilitative treatments have been well performed and that almost 20% of the range of motion recovered after surgery can be lost again later.

This is especially true when initial stiffness and joint anatomical changes are more pronounced.

Another key element is patient's motivation since he/she must be ready to undergo surgery and face the long re-educative course to reduce risk of recurrence or even worsening of initial stiffness.

We will now discuss elbow stiffness depending on its etiology.

Table 30.2 Stiffness orienting decision classification (SOD classification)

Prevalent type of stiffness	Surgery	Approach
Soft tissue contracture	Release	Arthroscopic
	Release (column procedure)	Open surgery
Secondary arthritis	Arthroscopic osteocapsular arthrolysis (mild or moderate)	Arthroscopic/open surgery
	Outerbridge–Kashiwagi (OK procedure) (severe or very severe)	Open surgery
	Biologic interposition arthroplasty (ex–fix) (severe or very severe)	
	TEA (>70 years)	Open surgery
Heterotopic ossification	Removal	Open surgery
Malunion/nonunion	ORIF/osteotomy	Open surgery
	TEA (>70 years)	Open surgery

30.7 Post-traumatic Elbow Stiffness

In a post-traumatic elbow stiffness, many elements need to be evaluated at the same time to decide the adequate treatment. Even for an expert and dedicated surgeon, it can be challenging to identify and define the algorithm he/she usually follows to define the best surgical treatment.

The existing classifications are descriptive, and they are not very useful to guide the type of treatment:

- Cause (intrinsic and extrinsic)
- Severity (very severe <30, severe from 30 to 60°, moderate from 61 to 90°, minimal >91°)
- Involved movement (flexion–extension/pronation–supination)

We can identify four factors to decide the surgical treatment:

1. Soft tissue contracture
2. Arthritis
3. Heterotopic ossification (HO)
4. Malunion/nonunion

Different "surgery guiding factors" can be present at the same time in a single patient.

For example, a patient with distal humerus malunion can also present a secondary arthritis, HO, and soft tissue contracture.

However, one of the four elements is usually predominant and influences the choice of the treatment.

We propose the following classification (the SOD classification), an easy and effective way to guide the treatment (Table 30.2).

30.7.1 Prevalent Type of Stiffness: Soft Tissue Contracture

Stiffness is mainly due to a reduction of the joint space, with hypertrophic and anelastic capsule and ligaments. An anterior and posterior capsulectomy must be performed, saving the ulnar bundle of the lateral collateral ligament (LCL) and the anterior bundle of the medial collateral ligament (MCL).

This arthrolysis can be performed both arthroscopically and open. The neurolysis of the ulnar nerve must be performed if there's any sign of chronic compression in the epithrocleo-olecranic groove or simply as a precaution when a recovery of over 30° is expected (to reduce the risk of postoperative neurapraxias). The subcutaneous anterior translocation of the ulnar nerve is rarely needed.

30.7.1.1 Arthroscopic Arthrolysis (Fig. 30.1)

The patient is in lateral decubitus or supine position, with pneumatic tourniquet at the proximal third of the arm. If needed, the neurolysis in the epithrocleo-olecranic groove can be performed with a small posteromedial incision.

Once the anatomic landmarks are done, 20–30 cc of saline solution are injected through the soft spot of the elbow (the space between olecranon tip, radial head, and the posterior edge of the lateral epicondyle).

We prefer to start with the anterior approach and access the joint through the anteromedial portal, while the instruments (shawer and radiofrequency ablator) are inserted through the anterolateral one.

The anterior joint space must be "recreated" removing the scar tissue from the articular surface and releasing the hypertrophic and anelastic capsule. The arthroscope and the instruments must switch places many times to complete the arthrolysis (from anteromedial to anterolateral and vice versa). An accessory portal (anterolateral or medial-proximal) as a tool to divaricate tissues during surgical maneuvering could be considered, but is not imperative.

Moving to the posterior approach, the accesses are posterior (trans-tricipital, about 3–4 cm from the olecranon tip) and posterior-lateral (close to the olecranon tip, where the end of the tricipital aponeurosis can be palpated). We suggest to initially insert the arthroscope through this last portal to work better and free the olecranon fossa from the scar tissue. Switching the instruments will allow to complete the

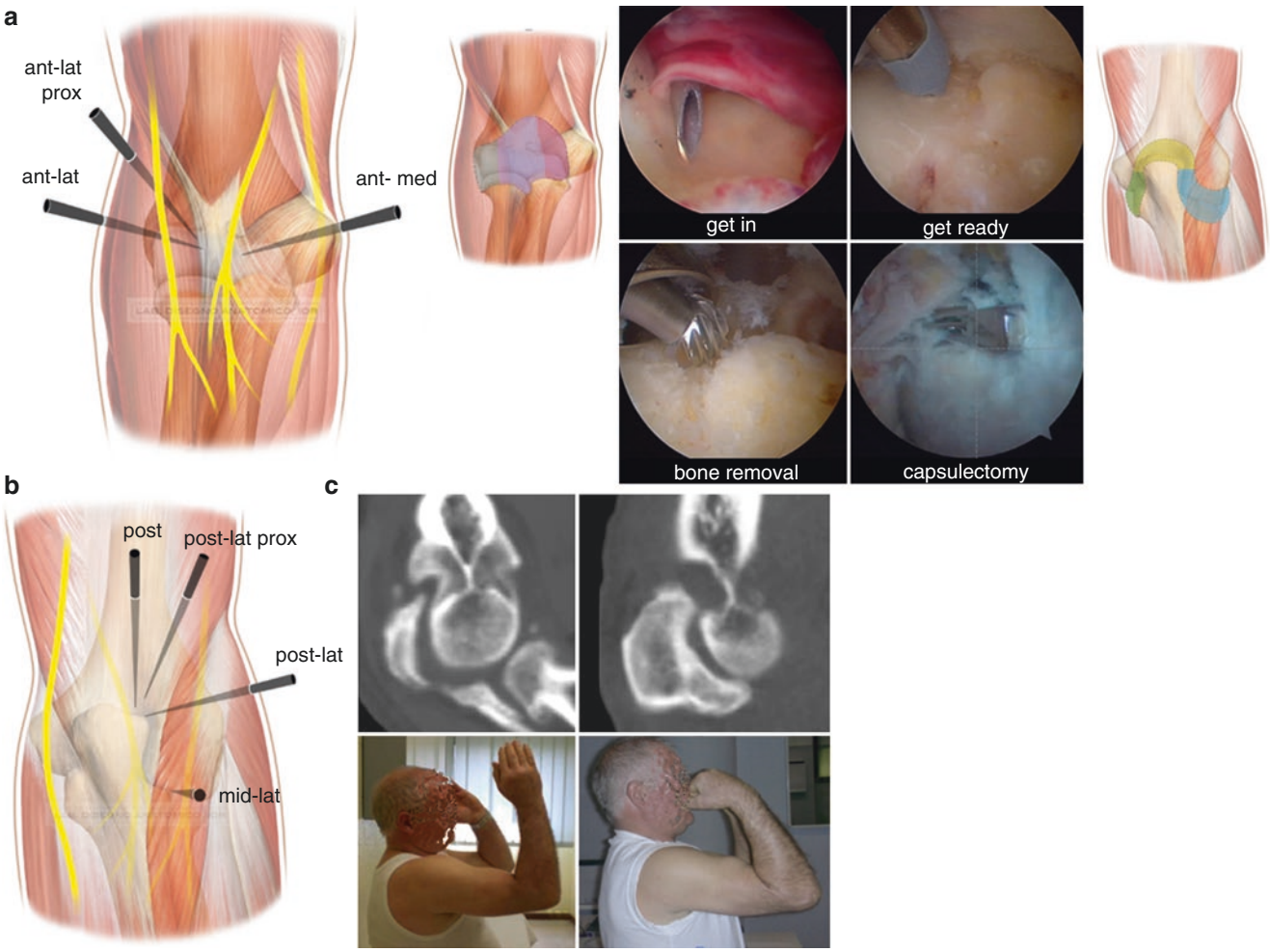


Fig. 30.1 Arthroscopic osteocapsular arthroplasty: arthroscopically is possible to manage anterior (**a**) and posterior (**b**) compartment by described portals. The stepwise sequence (get in, get ready, bone removal, and capsulectomy) is applied in each compartment to remove loose bodies/osteophytes (**c**) and the contracted capsule in order to improve the joint motion

arthrolysis on the posterolateral side. It is usually not necessary to reach for the posterior humeroradial joint as opposed to the osteocapsular arthrolysis that we will describe later on.

If the range of movement obtained is still not acceptable, the posterior bundle of the medial collateral ligament must be interrupted to obtain more flexion. This can be achieved in mini open surgery through the incision performed to free the ulnar nerve.

Anterior and posterior drains are set in place and will be removed about 48 h after surgery. The arm must be immobilized in extension with a cast, with pillow support, and with the hand kept 30 cm above the head for about 12–24 h, until the functional re-education begins.

Elbow arthroscopy is not recommended in patients who have undergone previous elbow procedures with changes to the normal anatomy.

Elbow arthroscopy after ulnar nerve transposition remains a relative contraindication. Steinmann et al. recommend extending the incision for the medial portal to identify and protect the nerve before inserting the arthroscope or instruments. An absolute contraindication for arthroscopic treatment of stiff elbows is a lack of experience with elbow arthroscopy. This procedure can be extremely difficult with a higher risk of nerve injury than other arthroscopic elbow procedures.

30.7.1.2 Open Arthrolysis (Fig. 30.2)

The patient is supine, with pneumatic tourniquet at the proximal third of the arm.

A choice has to be made between a single long posterior incision and two shorter incisions on the medial and lateral epicondyle. In case of single incision, the skin flap must be large enough to reach the two columns, but it means any subsequent surgery (fractures, new arthrolysis, arthroplasty, etc.) will have to adopt the same access. Performing two incisions allows for a less aggressive surgery on the soft tissues, reducing the risk of necrosis of the skin flap and postoperative pain and swelling, therefore favoring a better outcome.

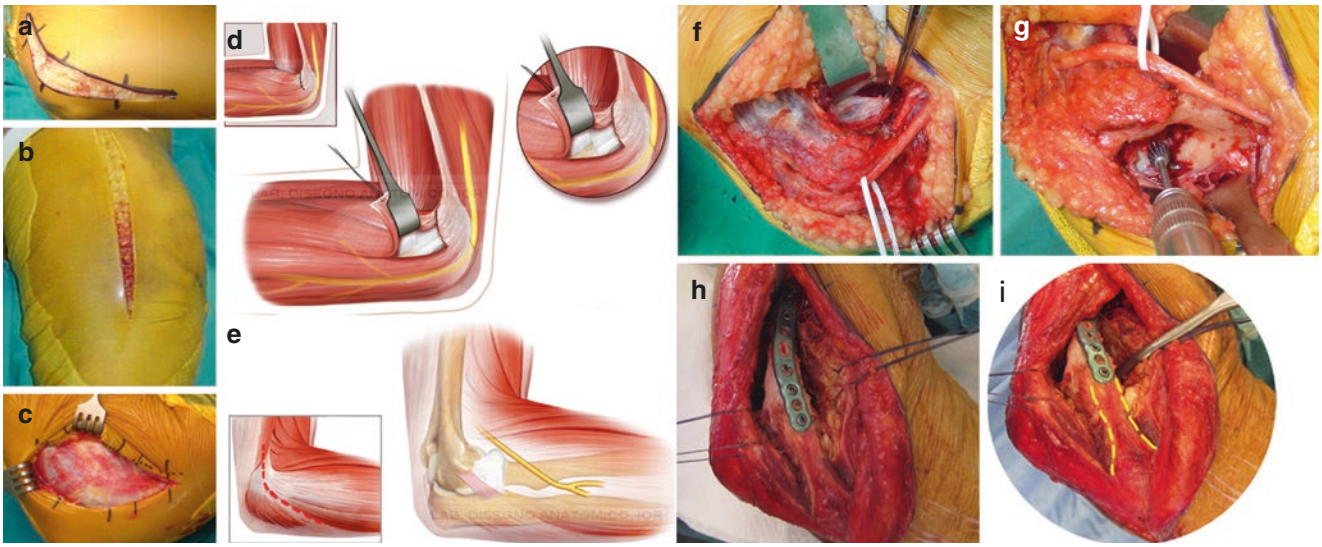


Fig. 30.2 Open arthrolysis. Both anterior and posterior aspects of the joint can be visualized as well as by medial or lateral column procedures. The skin incision could be posterior (**b**) or direct medial (**a**) or lateral (**c**). Imperative is to avoid lesion to medial and lateral ligament. So we suggest to reach the anterior (**f**) and posterior (**g**) camera for the medial column and the Kocher's approach (**e**, **h**, **i**) for the lateral ones

Independently of the incision choice, the ulnar nerve must be isolated in order to isolate the tendon of the triceps on the medial side and separate it from the posterior and posteromedial articular capsule. The same applies for the lateral side of the triceps in order to lift the muscle and its tendon. The posterior capsulectomy with the olecranon fossa cleaning is easily performed.

Once the posterior arthrolysis is finished, the anterior capsulectomy is next. Usually, either one of the two column procedures is sufficient. We suggest to start from the lateral side where the muscle is thinner. Through Kocher's approach (which protects the LCL), the humeroradial joint is exposed.

It is necessary to disconnect the epicondylar muscles to uncover and remove the anterior articular capsule. If the range of motion is still not acceptable, we can move to the medial side, extending the release of the ulnar nerve inside the flexor carpi ulnaris (FCU). The superior part of the FCU together with the medial condylar muscles must be laterally reversed to uncover the anteromedial side of the articular capsule. Once the sublime tubercle is identified, which lays just below the point where the ulnar nerve enters the FCU, the anterior bundle of the medial collateral ligament has to be protected. Although a partial or even complete capsulectomy is often recommended, there is little evidence that the results are better when compared with a simple capsulotomy.

The medial and lateral condylar muscles must be carefully reinserted with transosseous stitches after an accurate hemostasis. Again two drains (anterior and posterior) are positioned, followed by compressive elastic bandage with fixing in extension.

30.7.2 Prevalent Type of Stiffness: Secondary Osteoarthritis

The secondary stiffness related to osteoarthritis can be roughly divided into two groups:

- Mild or moderate stiffness, the joint line is preserved

The elbow is a joint able to develop a unique kind of osteoarthritis called "joint line sparring osteoarthritis." Traditional osteoarthritis begins with cartilage depletion followed by *subchondral geodes* and osteophytes. In this case instead, we can observe the growth of large intra-articular osteophytes filling the distal humeral epiphysis fossas (for the coronoid, the radial head, and the olecranon) and enhancing the volume of the bone bulges (coronoid and olecranon). These osteophytes represent a mechanical obstacle to the articular movement. X-rays and CT scan show a preservation of the joint space indicating that, once the mechanical impediment is removed, the humeroulnar joint could recover and maintain a good range of movement.

An accurate CT scan reveals a more complex situation:

– Frequent loose bodies in the anterior (between coronoid and its humeral fossa), posterior (between the olecranon and its fossa), and posterolateral (between the radial head and the capitulum) position
– Ligaments' insertion ossifications (humeral and ulnar LCL/MCL, ulnar anular ligament)

– Osteophytosic deformation of the olecranon profile from medial to lateral (Mickey Mouse ears), of the coronoid profile, and of the radial head and capitulum (Lim et al. 2008)

It is not simple or trivial to identify the original shape and recompose it. For this reason we take advantage of 2D and 3D CT scan reconstructions (Nishiwaki et al. 2013) to help us plan the surgical treatment described as "osteocapsular arthrolysis." In order to further improve the preoperative study, plastic models based on the 3D CT scan reconstruction can be produced (Fig. 30.3).

The osteocapsular arthrolysis surgery can be performed both arthroscopically (arthroscopic osteocapsular arthrolysis) and open.

The AOA (Fig. 30.1) is similar to the arthroscopic arthrolysis previously described but much more challenging for the following reasons:

- Entering the joint space, orienting the arthroscope and the instruments, setting up a working space, and identifying the anatomy are more arduous and therefore riskier.
- Maintaining the joint space open is mandatory to remove loose bodies and osteophytes; it is therefore necessary to introduce a spatula through the accessory portals (proximal anterolateral, anteromedial, and posterolateral). It is not recommended to increase the inflow pressure of the arthroscopic pump.
- It is necessary to perform the arthrolysis of the posterior humeroradial joint too. This is the most challenging site to work on; it must be explored from the posterolateral portal and the mediolateral portal (the soft spot).
- Osteophyte removal must be performed ahead of the capsulectomy. We suggest to use an osteotome to dislodge the osteophytes making the loose bodies to remove. Only at the end that we perform the reshaping with burr of the osteophyte margins and of the articular fossas. The burr produces a large amount of debris that might be the cause of subsequent ossifications.
- It is hard to decide how much bone to remove; it's better to remember that the removal of 3 mm of abnormal bone from the olecranon tip will improve extension by approximately 15°, provided there is no other pathology.
- The instruments must be switched from one portal to the other many times.
- The ulnar nerve release is routinely executed with the aim of working more safely on the medial side and performing the release of the posterior bundle of medial collateral ligament which cannot be achieved arthroscopically.
- The ulnar nerve may also be affected requiring decompression/transposition.

AOA can therefore only be used in selected cases, and the technique is demanding with a steep learning curve.

The open osteocapsular arthrolysis follows the same rules of the one described for the plain soft tissue contracture, except:

- The exposition of the two columns is nearly mandatory to completely remove the osteophytes (Fig. 30.2).
- If large osteophytes of the coronoid process are present, it's advisable to perform the Hotchkiss approach instead of the FCU split.

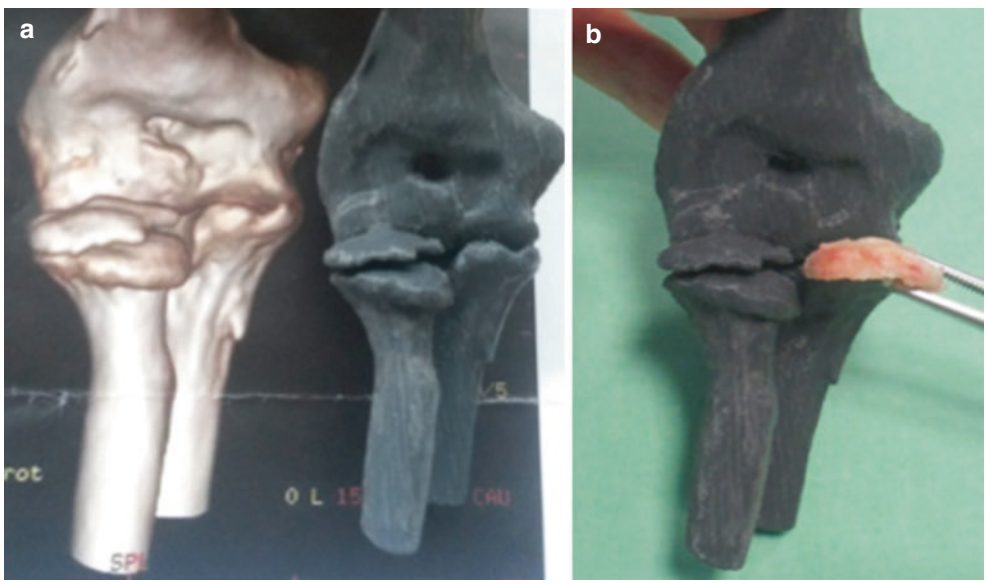


Fig. 30.3 Post-traumatic intrinsic elbow contracture with a big osteochondral fragment inside the joint. The 3D model molded on the CT scan helps to better plan the surgery (open or arthroscopic arthrolysis). It is possible to notice the correspondence among CT scan, the 3D model (**a**), and the removed fragment (**b**)

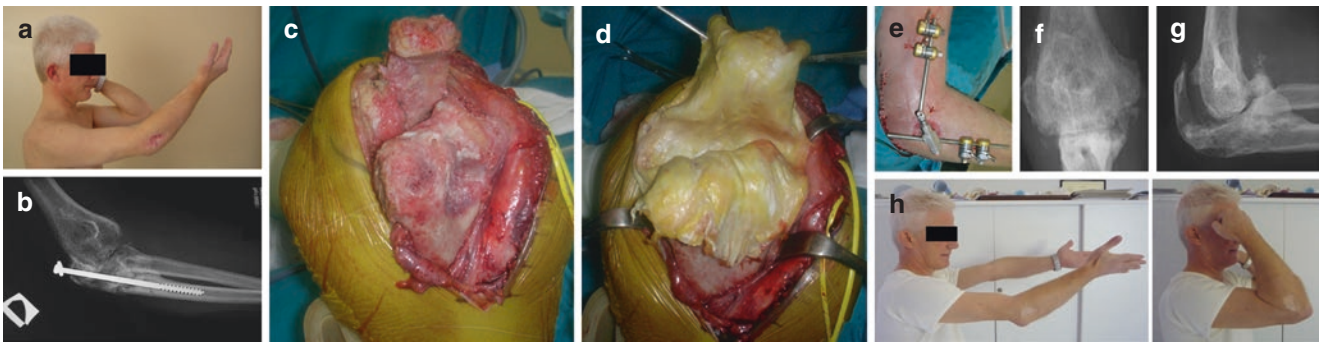


Fig. 30.4 Biological interposition arthroplasty. (**a**) Pre-op range of motion and (**b**) X-ray evaluation. (**c**) Intraoperative joint dislocation and arthrolysis. (**d**) Fascia lata covering articular surface. (**e**) The ex–fix to protect stability during postoperative active motion. (**f**, **g**) X-ray evaluation and (**h**) range of motion 7 years after surgery

- Keep an articulated external fixator ready in case the joint resulted unstable because of iatrogenic collateral ligament resection (anelastic, retracted, and sometimes ossified).

The opportunity of a mixed technique must be kept in mind: anterior arthroscopic arthrolysis + posterior open arthrolysis. This to reduce, the aggressivity of the surgical approach to free the anterior camera. If posterior osteophytes are small and there is no need for ulnar nerve neurolysis, a small transtricipital access might be acceptable for exposing the olecranon fossa and the osteophytes of the medial and lateral side.

Once the surgery is over, the treatment continues the same way described for the soft tissue contracture arthrolysis.

There is an alternative surgery technique that is currently out of fashion but must be remembered since effective in some indications: it's the Outerbridge–Kashiwagi (OK) technique.

By a triceps splitting approach, it is possible to obtain a wide view of the olecranon fossa. The anterior compartment can be accessed to a certain extent by creating a hole in the distal humerus, in the center of the olecranon fossa. The tip of the coronoid process can be debrided through the defect when the elbow is flexed. However, if sufficient release has not been achieved, a small additional incision can be made laterally and, if necessary, medially so that all compartments of the elbow joint can be reached.

- Severe or very severe stiffness: The humeroulnar joint cartilage is completely depleted, and the subchondral bone emerges in the joint.

The humeroulnar joint is severely compromised. If the patient doesn't complain about pain, surgical approach is not advised.

When the patient is more than 70 years old and has low functional requests, the total elbow arthroplasty (TEA) allows for a good recovery of the joint movement and resolution of the pain. However, the patient will have to closely follow the restriction imposed by the surgeon in order to reduce the risk of wear or mobilization of the prosthetic implant.

In younger manual working patients with painful incongruous joint surfaces and extensive intra-articular adhesions, only a salvage procedure is indicated. The so-called *biologic interposition arthroplasty* (Fig. 30.4) may require:

- A complete lateral ligament complex/extensor origin release to be able to separate the joint surfaces and achieve an adequate exposure
- Remolding the articular surface
- Covering the trochlea and the greater sigmoid notch by omologus membrane (fascia lata, Achilles tendon, etc.)
- An external fixator for at least 2 months for satisfactory correction

The aim of interposition arthroplasty is to reach a stable unpainful joint with an acceptable stiffness (around 50 degree of flexion–extension) in order to let the patients work again for a few years (Fig. 30.4).

30.7.3 Prevalent Type of Stiffness: Heterotopic Ossification

Heterotopic ossification is the formation of ectopic lamellar bone in soft tissues and is a poorly investigated sequela after trauma, brain injury, burns, or surgery. The disability incurred as a result of heterotopic ossification is quite variable.

The newly formed bone tissue follows the capsular bands and interstices between muscles, literally displacing the noble structures (nerves and vascular strands) as it grows. It is composed of mature new bone (lamellar under the microscope) and must not be confused with myositis ossifi-

cans (resulting from an intramuscular inflammatory process) or periarticular calcifications (amorphous calcium pyrophosphate collections without trabecular organization that is usually seen in the capsule and collateral ligaments).

These ossifications can either be very small or form bone bridges between the humerus and ulna or between the radius and ulna. They need to be isolated and removed in order to recover the movement.

The Hastings and Graham classification system uses clinical and radiographic data to categorize heterotopic ossification at the elbow into three classes (Hastings and Graham 1994) (Table 30.3).

Relying on the classification of forearm HO designed by Vince Miller, Jupiter and Ring (1998) subclassified Type I (proximal third) forearm synostosis into three types based on the location of ectopic bone: Type IIIA ectopic ossification is located at or distal to the bicipital tuberosity, Type IIIB involves the radial head and/or the proximal radioulnar joint, and Type IIIC is a proximal radioulnar synostosis. Viola and Hastings further subclassify forearm synostosis in: Subtype A, anterior involvement; Subtype B, posterior involvement; and Subtype C, intra-articular involvement of the proximal radioulnar joint (Viola and Hastings 2000) (Figs. 30.5 and 30.6).

HO have to be precisely classified on the based on the tac images and when they obstacle the joint movement have to be surgically removed. They are a relative contraindication to the arthroscopic arthrolysis every time nerves and vessels could be displaced by their presence. So open arthrolysis is the only possibility in most of the cases. Surgical approach is chosen case by case depending on the position and HO dimension. A preoperative CT scan is mandatory to schedule the procedure. In a few cases, a direct anterior approach is needed to remove the new bone formed among anterior cubital structures; also an external fixation could be necessary when it involves medial or lateral collateral ligament (Fig. 30.7).

Because of the possible recurrence, surgical excision of HO is usually delayed for 12 (6–18) months (from injury to operation) until the maturation of bone occurs knowing that clinical, laboratory, or radiographic indicators may not be reliable to reflect the state of HO. No guidelines have been published regarding the timing of removal, and the decisions remain on doctors' experiences. Furthermore, less satisfactory function can be expected after too late excision because of soft tissue contracture and muscular atrophy.

After the removal, a prophylactic management strategy is necessary, even if nothing can guarantee a perfect result or the absence of a recurrence.

Studies have demonstrated that NSAIDs (indomethacin, 25 mg three times per day for three to 6 weeks, or Cox-2 inhibitors) and radiation (700 to 800 cGy in a single fraction from 24 h preoperatively until 48–72 h postoperatively) are quite effective preventing heterotopic ossification with no statistical differences.

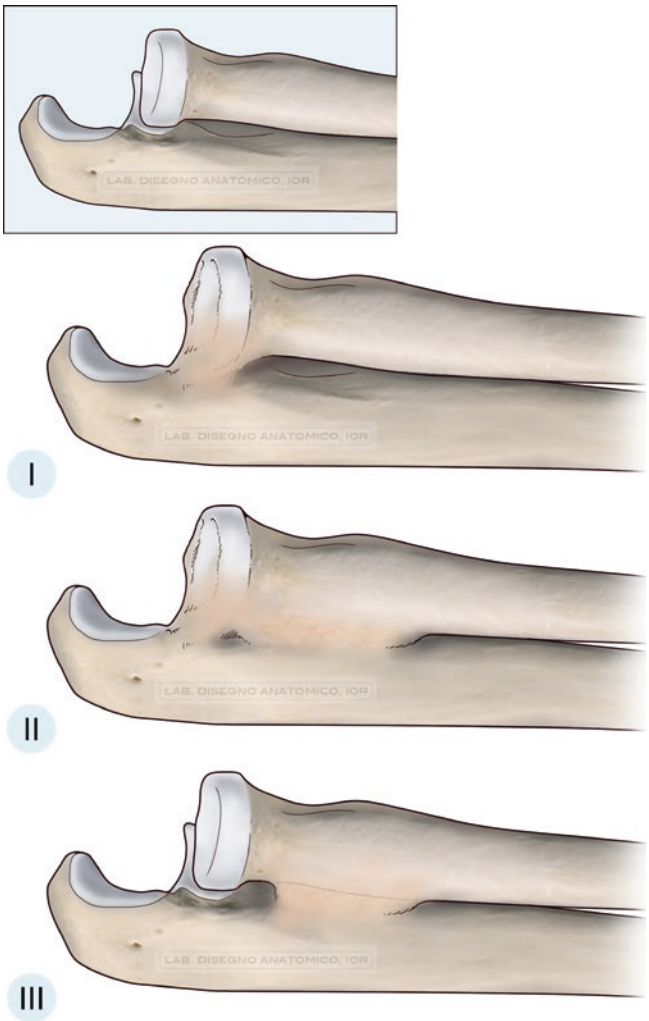


Fig. 30.5 Type I (proximal third) HO classification of forearm designed by Vince Miller, Jupiter, and Ring (1998) (Drawn by School of Anatomical Drawing, University of Bologna, Istituto Ortopedico Rizzoli). Type I ectopic ossification is located at or distal to the bicipital tuberosity, and Type II involves the radial head and/or the proximal radioulnar joint. Type III is a proximal radioulnar synostosis

Table 30.3 Hastings and Graham HO classification

Class I	Radiographic heterotopic ossification without functional limitations
	Radiographic heterotopic ossification with subtotal functional limitations
Class II	IIA: limited flexion–extension
	IIB: limited pronation–supination
	IIIC: limited in both planes
Class III	Radiographic and functional ankylosis
	IIA: ankylosis in flexion–extension
	IIB: ankylosis in pronation–supination
	IIIC: ankylosis in both planes

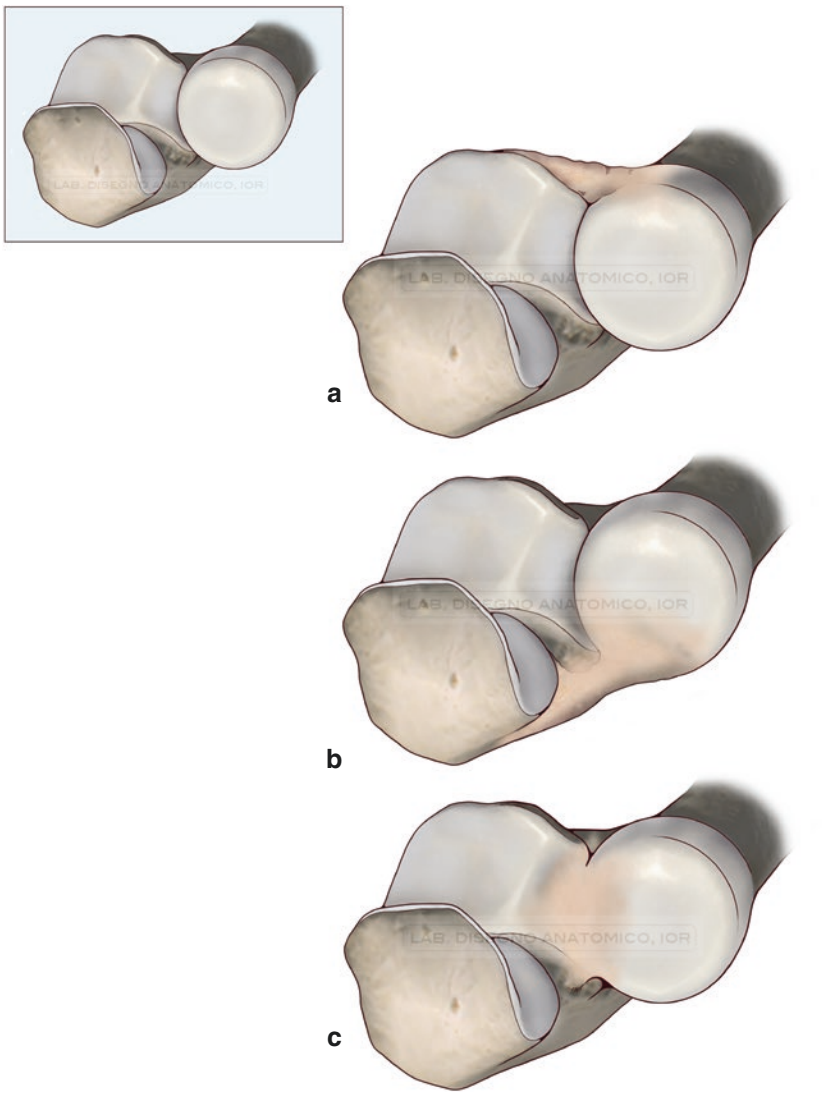


Fig. 30.6 Viola and Hastings further subclassify forearm synostosis (Viola and Hastings 2000) (Drawn by School of Anatomical Drawing, University of Bologna, Istituto Ortopedico Rizzoli): Subtype A, anterior involvement; Subtype B, posterior involvement; Subtype C, intra-articular involvement of the proximal radioulnar joint

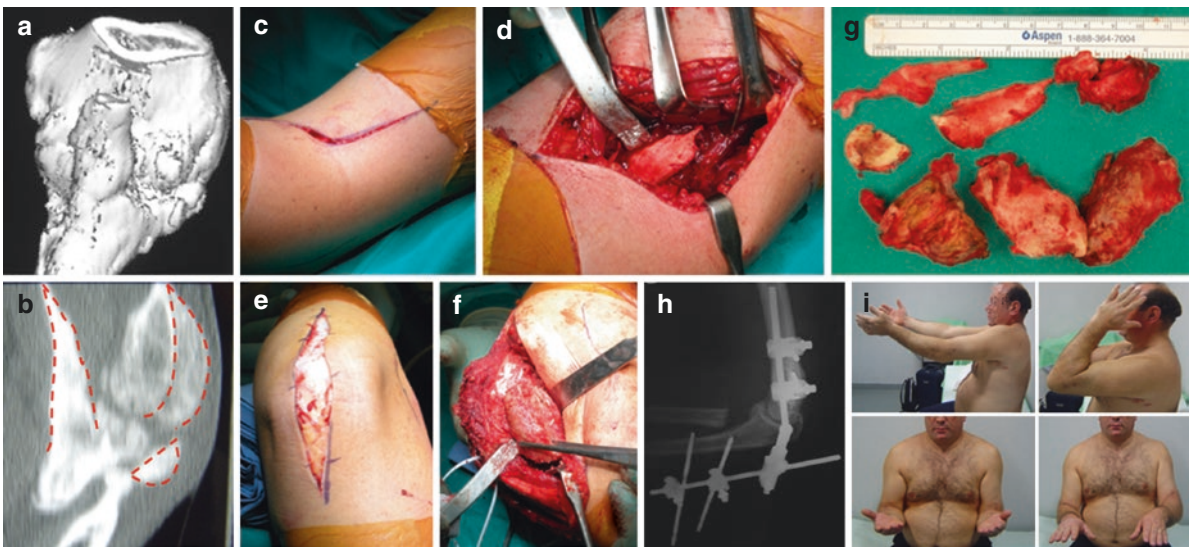


Fig. 30.7 Open arthrolysis by anterior and posterior surgical approaches. (**a**, **b**) CT scan preoperative evaluation. (**c**, **d**) Anterior and posterior (**e**, **f**) approach. (**g**) the amount of bone removed. (**h**) The ex–fix to protect stabily during postoperative active motion. (**i**) Range of motion 3 years after surgery

30.7.4 Prevalent Type of Stiffness: Fracture Malunion/Nonunion

In case of an over-/intercondylar elbow fracture with stiffness at 6 months from conservative or surgical treatment, CT scan evaluation will be looking for signs of malunion or nonunion. If the fracture subverted, the shape of the trochlea stiffness is intrinsic, and surgery is not a viable solution. When throclea and capitulum are not distorted and the malunion only affects the inclination of the articular spool with respect to the longitudinal humeral axis, a corrective osteotomy can be considered. The approach will be triceps sparing in case of a single-plane osteotomy, while a TRAP approach or olecranon osteotomy will be needed in the event of a multiple-plane osteotomy (which is much more challenging). Once the osteotomy (closing wedge) is completed and an acceptable anatomy is restored, synthesis will be performed with one or two plates, parallel or at 90° (Fig. 30.8). The post-op period will be similar to the one described in the "Fractures" chapter.

Osteotomies are challenging procedures and we cannot guarantee any result to the patient; therefore, the indication must be extremely selective, case by case.

Nonunions or psudoarthrosis are extremely challenging situations too. First, the presence of infection has to be excluded via multiple blood culture, scintigraphy, and eventually antibiotic essay from an eco-guided fine needle aspiration. Once the infection is excluded, a curettage of the nonunion site must be performed in order to reach a bleeding bone surface. Matching surfaces and obtaining a stable synthesis often mean bone stock loss and alterations of the anatomy, inevitably affecting at least part of the range of movement.

There is an indication for TEA in patients over 70 with distal overcondylar pseudoarthrosis.

30.8 Arthritis

30.8.1 Primary Osteoarthritis

Primary osteoarthritis is related to a multifactorial genesis (familiarity, functional overload, mild instability, loose bodies, etc.).

It has been proved by mechanical studies that functional load spreads on the joint surface in a different way whether the articulation is in flexed or extended position (Rettig et al. 2008).

Work activity involving vibrating tools and sport activities with overhead throwing have different ways to put a strain on the humeroradial and humeroulnar joints.

The joint, slowly damaged over a long period of time, usually comes to our attention due to a progressive reduction of range of motion.

The distinction between arthritis with or without joint line preservation that we described for post-traumatic stiffness also applies for primary osteoarthritis, as well as for its treatment.

30.8.2 Inflammatory-Based Secondary Osteoarthrosis

Rheumatoid arthritis comes to our attention when conservative treatments cannot control pain anymore.

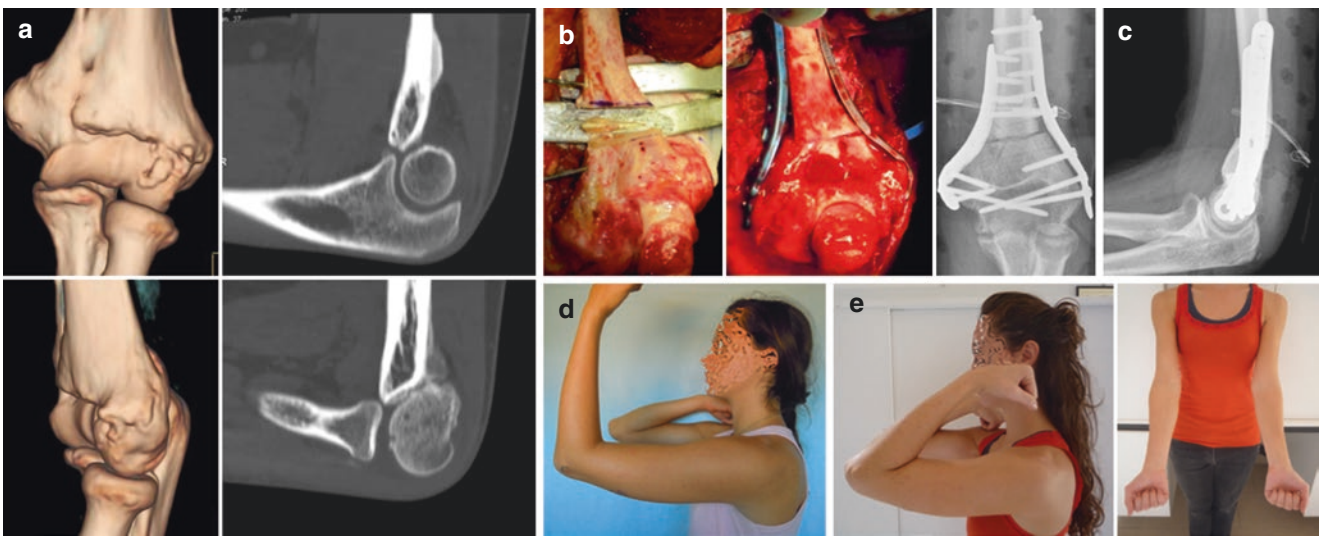


Fig. 30.8 Corrective malunion osteotomy. (**a**) CT scan preoperative evaluation. (**b**) Intraoperative wedge osteotomy and internal fixation by congruent plates. (**c**) Postoperative X-ray evaluation; (**d**, **e**) range of motion, respectively, at three and 12 months after surgery

In the first stages, when the joint is not deformed but the hypertrophic synovial membrane reduces movements causing both a mechanical impediment and intense pain during flexion–extension, surgical synovectomy can provide a partial (and sometimes total) relief for an undetermined period of time (sometimes a few years).

Synovectomy can be performed arthroscopically as well as open. The more aggressive open surgery allows for better biopsies when needed to better typify the rheumatic disease. Arthroscopic surgery is not dissimilar from arthrolysis surgery, but it remains more delicate due to the weakness of the capsular component and the poor muscle mass of these patients (both factors that restrict the arthroscopic treatment to the expert surgeon, given the higher risk for neurovascular structures).

In the event that the joint is already severely compromised, total replacement is the only effective option, with all the known limitations.

30.8.3 Others (Neurogenic Elbow Stiffness, Tumor, Etc.)

Joint stiffness can have many other causes.

Since there is no room for an extensive coverage, we limit to a rare, but not so unusual, tumoral based cause of joint stiffness: the articular and periarticular osteoid osteoma.

It must be taken into consideration when the patient reports progressive worsening stiffness emerged with pain during months (sometimes years), stronger at night and well responding to NSAIDs.

NMR (if adequately powerful and executed) together with thin layer CT scan and Tc-99m whole-body scintigraphy usually allow for an accurate diagnosis.

Today, treatment is usually exclusive to the interventional radiology which, thanks to the CT scan-guided thermal ablation, is able to avoid the need of a surgical excision.

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Elbow Stiffness: Rehabilitation Management

31

Silvia Di Giacomo

31.1 Rehabilitation Management

Elbow stiffness due to elbow or shoulder trauma is a difficult condition to treat. Unlike idiopathic and secondary shoulder stiffness, which are often amenable to appropriate manual physiotherapy, this form seldom benefits from physical therapy, especially if it is severe or very severe (Charalambous and Morrey 2012; Giannicola et al. 2014). Yet it is quite frequent, arising both in patients managed conservatively and in those treated by surgery.

Management of wrist or shoulder joint injury often involves elbow immobilization with braces that hold it in 90° of flexion. Wearing such braces for longer than a week has the potential to induce elbow stiffness; if the patient has an especially anxious disposition and moves very slowly and carefully, even a week may give rise to stiffness (King et al. 1993; O'Driscoll and Giori 2000). Moreover, in case of a shoulder fracture, fracture bleeding combined with elbow immobilization in 90° of flexion will result in blood collection and oedema at the level of the elbow, similar to the way water stagnates in the L pipe of a sink (Carli and Di Giacomo 2013), further promoting stiffness (Fig. 31.1). These haematomas may evolve into a calcification that can then be managed only by surgery.

This is why over the past few years replacing plaster casts with removable braces has proved a winning strategy also in the case of elbow rehabilitation, because they enable passive mobilization of the joints adjacent to the injured area even during the phase when absolute immobility is required. Immobilization has the potential to induce stiffness also in patients with direct elbow trauma. Here, too, dynamic orthoses are preferred to static ones (Merolla et al. 2014) (Fig. 31.2) also in patients with radial head fracture, medial or lateral ligament lesion, dislocation, and elbow surgery. The brace will be removed by the therapist at the time of the first rehabilitation session, to mobilize the wrist, shoulder, and upper thoracic outlet 2–3 times weekly, which will also promote tissue drainage and vascularization (Brach and Goitz 2006). Immediate passive mobilization is the first, key step to ensure a satisfactory outcome and full recovery.

Elbow stiffness may be induced by all elbow conditions, be they secondary to trauma or to surgery (King and Faber 2000; Timmerman and Andrews 1994). In these situations, risk of stiffness is even higher if the elbow is not early and appropriately mobilized in relation to the underlying injury; stiffness may arise as a complication.

Whether the elbow trauma has been managed conservatively or surgically, the rehabilitation programme during the early stage of mobilization (Wu et al. 2014) will be determined by the injury:

In patients with radial head fracture treated conservatively, pronation-supination will be avoided, and mobilization in flexion-extension will be extremely gentle (0–40° of flexion; 0–40° of extension starting from 0°, with the hand in neutral position); in patients with simple dislocation and a ligament injury treated conservatively, rest is essential over the first week; passive mobilization of adjacent joints and—if the pain permits — of the elbow is initiated on the second week; special care is devoted to forearm position, to favour healing of the injured ligament;

In patients treated surgically, the rehabilitation therapist will follow the surgeon's prescriptions; in cases where extended immobilization is recommended, at least the wrist and shoulder should be mobilized to avoid the onset of stiffness. Skeletal fractures stabilized surgically should also be mobilized early, with timing and

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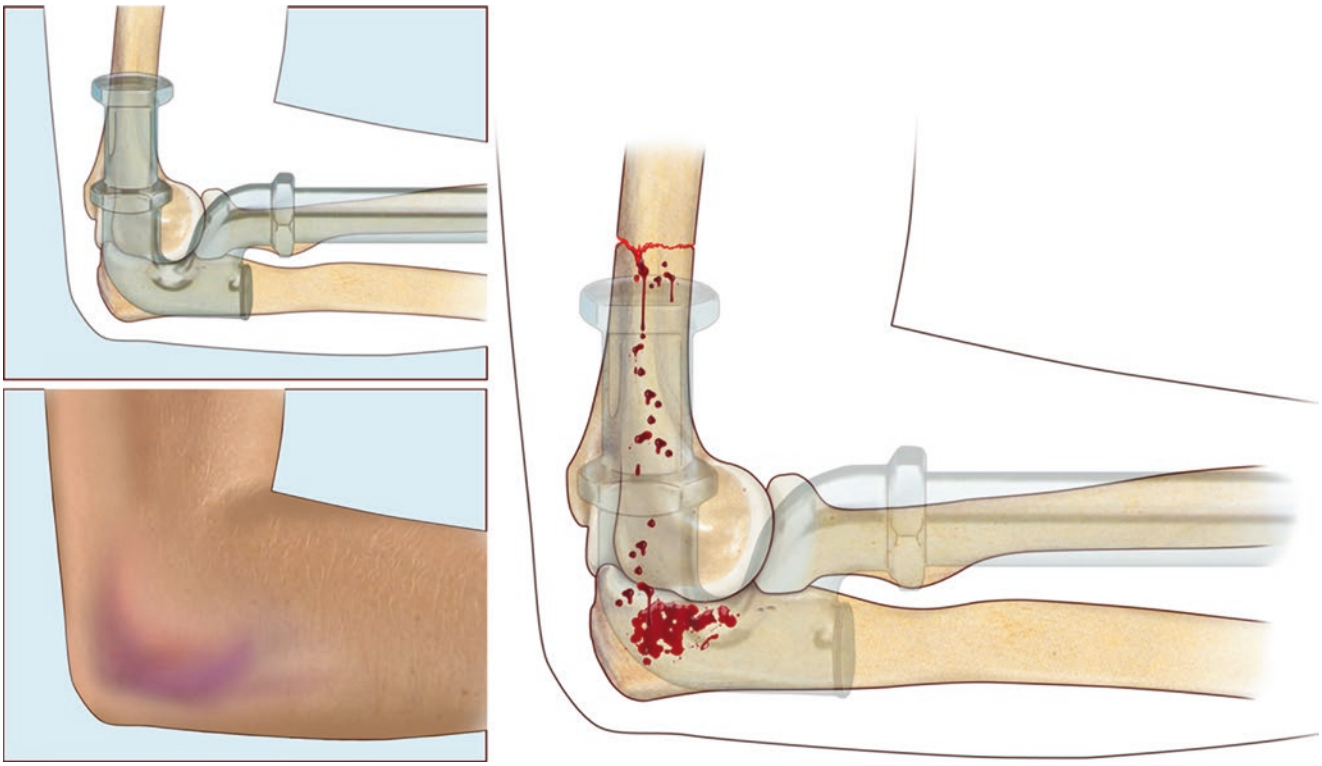


Fig. 31.1 Humeral fracture with the elbow held in 90° of flexion. Illustration of bleeding and fluid collection predisposing to stiffness development

exercises based on the type of procedure. In his diagram, Protzmann (1980) highlighted that immobility exceeding a week is associated with a greater functional impairment.

Stiffness is not necessarily commensurate to trauma severity, be the injury treated conservatively or surgically (Fusaro et al. 2014b). Small bony lesions that are almost invisible radiographically may involve severe tissue stiffness that is not amenable to manual physiotherapy, whereas patients with severe lesions treated by surgery may recover satisfactory passive and active limb range of movement (ROM). (Figs. 31.3, 31.4, and 31.5).

A narrow ROM in extension normally entails a predominantly aesthetic impairment, whereas a reduced ROM in flexion entails a functional impact on daily living activities (Figs. 31.6, 31.7, 31.8 and 31.9).

ROM loss secondary to a surgical procedure may be induced by:

Capsule thickening and loss of elasticity
Capsular contracture
Adhesions involving the capsule and articular cartilage surfaces
Fibrosis
Ossification of collateral ligaments and heterotopic ossification
Muscle contracture
Ossifying myositis
Olecranon fossa oedema

In the post-operative (p.o.) period, after brace removal, physiotherapy sessions are scheduled at least twice weekly. At this stage tissue assessment is critical. Already at the time of the earliest movements, the expert therapist can predict



Fig. 31.2 A patient with osteochondritis dissecans wearing a dynamic orthosis after implantation of an autologous rib graft (pictured 1 week from surgery)

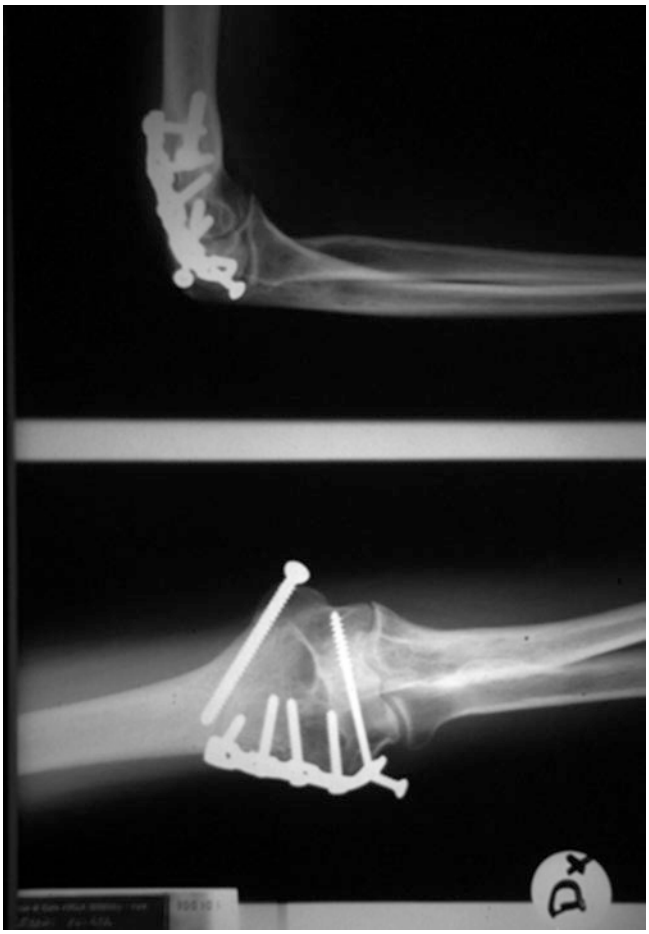


Fig. 31.3 Radiography in a patient with large fracture. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.4 A patient with a large fracture managed with screws has recovered optimum ROM in extension. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

whether the elbow is evolving to stiffness or mobility. If the tissue is becoming dense and passive movement is painful, mobilization will have to be performed three times weekly (Fusaro et al. 2014b; Takhashi et al. 2011). However, the joint should not be forced, to avoid the risk of augmenting the stiffness; since it is a complex joint with a limited ROM, mobilization shall have to be performed often but gently. In this phase the therapist's experience and palpation sensitivity will guide them in establishing the appropriate exercise intensity that affords the best results with as little pain as possible (Takhashi et al. 2011). Before sessions, the joint should be warmed (for about 20 min) with a damp, lukewarm towel to prepare it for manipulation (Fig. 31.10).



Fig. 31.5 A patient with a large fracture managed with screws has recovered optimum ROM in flexion. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.6 A patient with severe extension limitations entailing disability in some activities of daily living but above all he has an aesthetic problem. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.7 A patient with severe flexion limitations can't arrive to wash his face. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.8 A patient with severe flexion limitations entailing disability in some activities of daily living. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.9 A patient with severe flexion limitations can't arrive to touch his ear. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

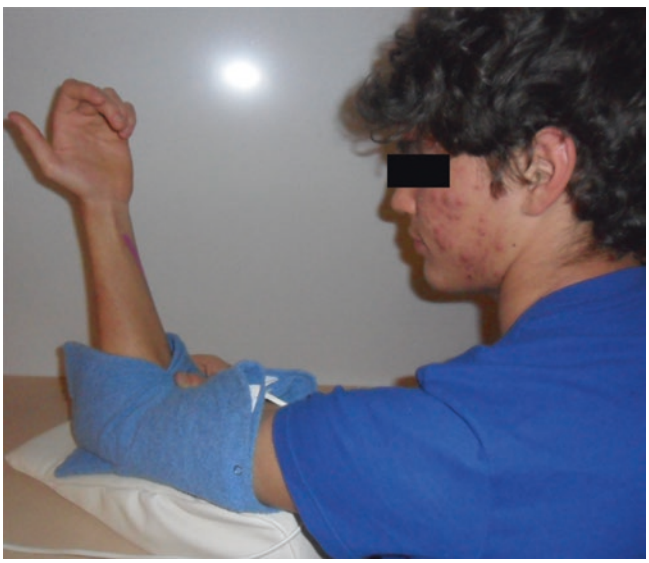


Fig. 31.10 A patient warming the joint with a damp, lukewarm towel before passive mobilization

31.2 Long-Standing Stiffness

Some patients come to the attention of the rehabilitation therapist with long-standing stiffness. Their first question is will my elbow improve? Will I be able to move it as before? The key facts to be established are whether the stiffness is intrinsic, extrinsic, or mixed; whether it is poor, moderate, severe, or very severe; the time elapsed from the trauma/procedure and the current evaluation, patient age, and the type of physical therapy applied until then, if any.



Fig. 31.11 A young basketball player during the match

In patients with severe or very severe stiffness, the therapist will have to determine whether manual rehabilitation can ameliorate the condition or whether a capsule release procedure is required (Bonutti et al. 1994; Michlovitz et al. 2004; Pignatti et al. 2000). The key criterion in such cases is the state of tissues. Over the past two decades, studies of glenohumeral injury management have found that retracted periarticular tissue (capsule, ligaments) generates intense pain that radiates along the limb. This also applies to the elbow. Painful passive mobilization is a significant symptom, encouraging the therapist to make a further attempt at manual rehabilitation even if the patient has been doing physiotherapy for months; this applies especially to operated joints. A patient with a stiff elbow, where passive mobilization elicits little or no pain in the joint or along the arm, may be with joint crepitus, has a stiff joint, not tissue stiffness, and the scope for ROM improvement is very limited.

Another factor that needs to be taken into account is whether the patient has been treated conservatively or surgically, since another surgical procedure must be avoided at all cost. The diagram reported below shows that functional recovery is enhanced if the variables on the two axes, i.e. time from trauma and healing process, form two adjacent curves, i.e. are themselves close. Since the repair process cannot be hurried, one parameter that can be affected is time to functional recovery, which can be reduced.

The first 2 months of rehabilitation after a trauma/operation are critical (Fusaro et al. 2014b). Patients with severe or very severe stiffness who are referred to the therapist after this interval, especially young, sport-practising patients, will not achieve a satisfactory outcome without surgery (Figs. 31.11, 31.12, 31.13, 31.14, 31.15, and 31.16).



Fig. 31.12 Brace after surgery

How then should elbow stiffness be managed?

According to the literature, it should be managed with surgical approaches (Brach and Goitz 2006; Moro and King 2000; Morrey 1992), series of braces, passive mobilization, and day and night static braces (Veltman et al. 2015; Fusaro et al. 2014a; Jupiter et al. 2003; Schwartz 2012).

It should be noted that when managing stiffness, the principle of treating the patient as a whole is temporarily superseded by the need for addressing the local condition. Clearly, work on posture does provide benefits, but the decisive element is treatment of the elbow joint using specific grip techniques acting along the force lines of the different elbow movements:



Fig. 31.13 A young basketball player suffered an elbow trauma and left ulnar collateral ligament (UCL) injury during a game; 2 months later he developed elbow stiffness in flexion despite rehabilitation three times weekly



Fig. 31.14 Residual elbow stiffness in extension after UCL reconstruction by the docking technique was followed by passive mobilization already on the first p.o. day, to avoid a recurrence



Fig. 31.15 The player 4 month from surgery, after daily physiotherapy in a rehabilitation pool, passive mobilization, and daily self-assisted exercises every 2 h



Fig. 31.16 ROM 4 months from the operation; this goal would never have been achieved without surgery and an intensive physiotherapy programme

Grip technique for flexion (Figs. 31.17, 31.18, 31.19, and 31.20)
Grip technique for extension (Figs. 31.21, 31.22, and 31.23)

- Grip technique for supination: the therapist's hands form a pair of forces, thus avoiding making a lever only on the wrist by applying also a proximal grip (Fig. 31.24).
- Grip technique for pronation: the therapist's hands form a pair of forces that avoid making a lever only on the wrist by applying also a proximal grip (Fig. 31.25).

Flexion and extension may be executed with the patient's hand in neutral position, pronated, or supinated. Combining two movements executed in different planes is recommended when trying to recover the last few ROM degrees, but may be painful in the early mobilization period.

Awareness of the procedure undergone by the patient is critical to select the most suitable grips.



Fig. 31.17 Grip technique for flexion if there is shoulder compensation. the therapist's support is on all forearm of the patient.



Fig. 31.18 Detail hand position during the flexion tecnique if we want to increase thrust intensity and avoid shoulder compensation



Fig. 31.19 Grip tecnique for flexion if there is not shoulder compensation



Fig. 31.20 Detail of the proximal grip

Precautions to be taken during elbow mobilization include the following:

If a plaque and screws or a prosthetic stem has been applied, the grip will be below the plaque, because making a lever above the plaque may result in bone fracture (Figs. 31.26, 31.27, 31.28, and 31.29).

Passive mobilization of a painful, stiff elbow should avoid movements that involve different planes, i.e. flexion and supination or pronation, because they entail greater tissue pain that risks discouraging the patient; such movements are allowed after recovery of the intermediate ROM degrees, to achieve further gains. In the early phase, movements will therefore be confined to physiological planes, such as flexion, extension and — with the elbow in 90° of flexion — supination and pronation.



Fig. 31.21 Grip technique for elbow extension



Fig. 31.22 Detail of the elbow extension grip



Fig. 31.24 Elbow supination grip and grip technique for supination



Fig. 31.25 Elbow supination grip and grip technique for pronation

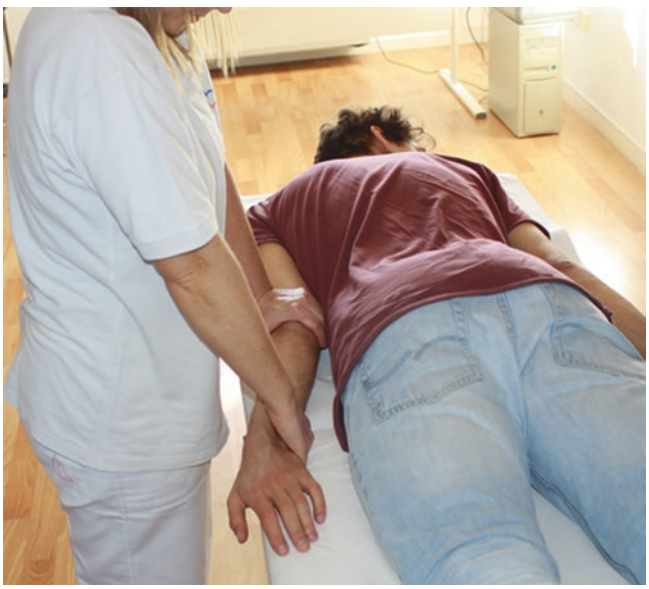


Fig. 31.23 Grip technique to improve the last degrees of elbow extension



Fig. 31.26 X-ray sequence in a elbow fracture before surgery. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.27 X-ray sequence after surgery. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.28 X-ray sequence of a lesion treated with plaque and screws where a fracture above the plaque was determined by an inappropriate grip during mobilization. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.29 The same fracture after 20 days of rest with bone callus. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino

Mobilization of the wrist in flexion, extension, and ulnar and radial deviation should always be included.

The shoulder should consistently be mobilized in all planes of movement: protraction, retraction, and external and internal rotation at all angles.

Only proximal grip techniques should be applied.

The forearm should be hugged, not held in the hands, to reduce pain (allodynia). According to Melzack and Wall's gate theory of pain, stimulation of joint and muscle elongation activates pain receptors, generating a nociceptive stimulus that is modulated by the central nervous system. Hand pressure on the painful area activates cutaneous sensory neurons that respond to the mechanical and pressure stimuli and inhibit the pain fibres stimulated by elongation, thus allaying pain in the area. This principle, which explains why we spontaneously compress painful areas of our body (e.g. our abdomen in case of abdominal pain), is exploited by the therapist, who holds the painful area with a hugging grip.

Beginning on the 30th day from the operation/trauma, careful instruction by the therapist enables patients to begin self-assisted passive mobilization exercises in flexion and extension every 2 h in a series of 10 (Figs. 31.30, 31.31, 31.32, and 31.33).

Recovery of the last 20° of passive ROM, especially in young patients who still exhibit elbow stiffness 3 months from surgery/trauma, can be helped by night bracing. A tailor-made brace, worn at night after rehabilitation sessions and remodelled after a week, helps stabilize the gains of manual treatment. The approach has been found effective both for extension and flexion (Veltman et al. 2015; Fusaro et al. 2014a; Müller et al. 2013) (Figs. 31.34, 31.35, 31.36, 31.37, and 31.38) and can be adopted for 6 up to 16 months from surgery/trauma.



Fig. 31.30 Self-assisted mobilization exercises to be performed at home at 2 h intervals in the first period after surgery (about 50 days)

As soon as the patient achieves the ROM degrees that are indispensable for active movement (50° to 140° degree), they can follow a programme of active exercises with therapist supervision to recover normal fluid movement and strength (Figs. 31.39, 31.40, 31.41, 31.42, 31.43, 31.44, 31.45, 31.46, and 31.47).



Fig. 31.31 Self assisted mobilization exercises for extension, to be performed at home at 2 h intervals, in the first period after surgery



Fig. 31.32 Self assisted mobilization exercises in flexion to be performed at home at 2 h intervals



Fig. 31.33 Strong self assisted mobilization exercises to be performed at home at 2 h intervals

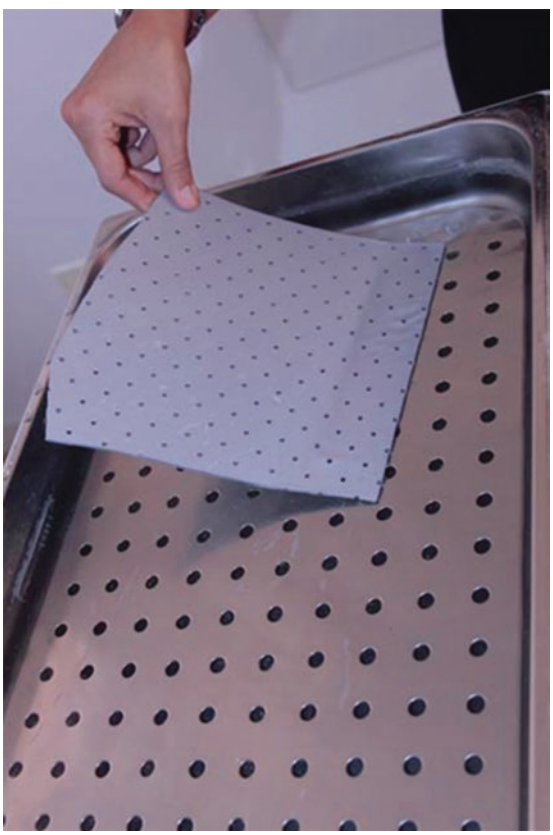


Fig. 31.34 Construction equipment for thermoplastic brace, custom-made immediately after the rehabilitation session to be worn by a patient with stiffness in extension. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.35 Thermoplastic brace, custom-made immediately after the rehabilitation session to be worn by a patient with stiffness in extension. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.36 Thermoplastic brace, custom-made immediately after the rehabilitation session to be worn by a patient with stiffness in extension. Reproduced with permission from Carli D, Di Giacomo S (2013), Preparazione atletica e riabilitazione. Edizioni Medico Scientifiche, Torino



Fig. 31.37 A patient with a stiff elbow in flexion is wearing a flexion brace with straps that prevent forearm extension



Fig. 31.38 Another vision of a patient with a flexion brace with straps that prevent foream extension



Fig. 31.39 Exercises direct at recovering strenght in left elbow



Fig. 31.40 Exercises directed at recovering strenght using body weight



Fig. 31.41 Exercises directed at recovering the proprioception in the elbow after surgery



Fig. 31.42 Exercises directed at recovering normal fluid movemnt in extension



Fig. 31.43 Plyometric exercises for elbow after surgery

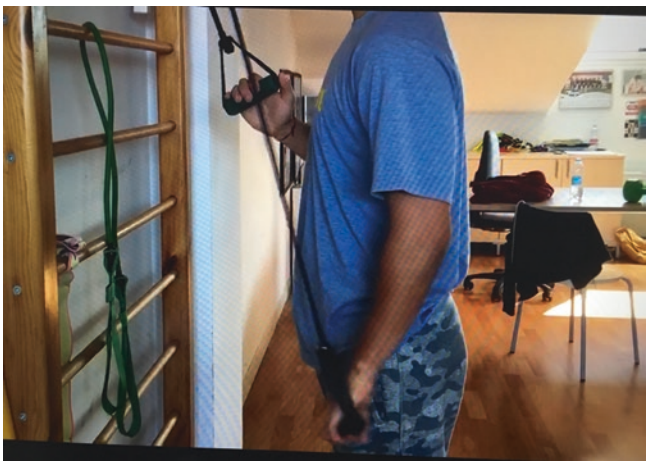


Fig. 31.46 Exercises directed at recovering strenght in extension



Fig. 31.44 Exercises directed at recovering fluid movement in flexion



Fig. 31.47 Exercises dirested at recovering strenght in extension against gravity



Fig. 31.45 Exercises directed at recovering strenght in flexion

Rehabilitation highlights

Elbow stiffness

conservative APPROACH — postoperative APPROACH

brace, not plaster cast
early passive mobilization (complete immobilization not exceeding 3 days)
appropriate grip techniques
exercises to recover normal, fluid movement
night brace in flexion or extension 3 months from trauma
self-administered exercises at 2 h intervals throughout the day from day 30

GOLD STANDARD:
STIFFNESS PREVENTION

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Postoperative Pain Relief

32

Battista Borghi, Andrea Tognù,
Sandra Giannone, and Pina Gallerani

The approach toward postoperative pain has radically changed in the last years: once considered an inevitable symptom, of secondary relevance within the surgical procedure, it is now a key feature of the patients' surgical pathway.

This shift has been determined by clinical, ethical, and organizational reasons.

From a clinical standpoint, it has been demonstrated that appropriate pain management has a positive impact on postoperative outcome and may prevent the onset of functional deficits and chronic pain.

From a deontological point of view, since it is nowadays relatively easy to effectively manage postoperative pain, it would be unethical for the physician not to take care of this aspect with maximum attention.

Regional anesthesia, e.g., continuous infra- or supraclavicular brachial plexus block, is a mainstay of postoperative pain management in elbow surgery.

32.1 Supraclavicular Brachial Plexus Block

Supraclavicular brachial plexus block has regained its deserved popularity with the widespread use of ultrasound-guided block techniques: since both the neural structures and the pleura can be easily visualized, the risk of pneumothorax is much lower than with conventional neural stimulator-based technique (Tognù 2013).

Besides, supraclavicular echo-guided block can be easily performed even in morbid obese patients.

Another advantage of this block is that it does not require a particular patient position, so it is quite comfortable to perform in fractured patients who may have considerable pain upon mobilization.

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This technique provides effective anesthesia for the whole arm in a few minutes and has therefore been given the epithet of "the spinal of the arm."

For all these reasons, we have almost completely abandoned the use of axillary block in our daily practice.

32.1.1 Patient Position

The patient lays supine with the head facing the opposite side of the block. In some cases, and particularly in obese patients, it may be useful to place the patient in semiupright position.

Probe and needle:

- Linear high-frequency probe set between 12 and 18 MHz
- Single shot: 50 mm length (22 g) needle. Continuous block: 18 g Tuohy needle, 50 mm length

32.1.2 Ultrasound Scan

The probe marker should conventionally be placed to the right side of the patient, but, in our opinion, this choice should be left to the single operator.

In the supraclavicular fossa, place the probe parallel to the middle third of the clavicle, and tilt the transducer in a slightly caudal direction. From here, move medially or laterally until the subclavian artery is visualized in its shots axis as a circular hypoechoic and pulsatile structure (when in doubt, confirm with *Power Doppler*). Posterior to the vessel, the first rib will appear as a hyperechoic line with a dark acoustic shadow deep to it, due to the fact that the osseous structure blocks ultrasound passage.

The small arch formed by the first rib with its acoustic shadow interrupts another hyperechoic line underneath, which is in turn crossed by the ultrasound beam, generating reverberation artifacts. These artifacts, named comets, are typical of the air-tissue interface (lung parenchyma), and their hyperechoic lining is the parietal pleura. In most

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patients, the distance from the skin to the pleura in the supraclavicular fossa is smaller than 3 cm.

Lateral to the artery, trunks and divisions can be seen. In the short axis, they appear as a variable number (between 5 and 7) of hypoechoic round or oval structures, which form a typical triangular grape-like image, with its tip facing laterally (Fig. 32.1). The nervous trunks are enveloped at this level by a fascial sheath, which is the direct prosecution of the cervical fascia.

32.1.3 Technique

The brachial plexus lies superficial at this level, so it is not necessary to have a particular angle of attack for the needle. A distance of 2–3 cm from the probe is usually optimal to allow needle advancing as parallel as possible to the ultrasound beam; this way, the tip pf the needle should always be visible (never proceed if the tip is not under vision). If the tip of the needle is not visible, the probe-needle axis needs to be adjusted by pressure application/release, rotation, and tilting; in this phase it is very useful to use small pilot local anesthetic boluses and jiggling movements. The needle must be slowly advanced until it touches the fascia that surrounds the plexus, which, when not clearly visible on ultrasound, is searched by applying pressure on it and determining its introflexion. At this point, further light pressure on the needle will allow the needle to enter the fascia: the access into the sheath will be not only visible on the ultrasound image but also felt with a distinct "click" on the needle. After a negative aspiration test, 1 mL of local anesthetic will be injected: the injection must be smooth without resistance and must not cause pain. A total volume of 15–20 mL of local anesthetic will be injected, carefully observing appropriate hypoechoic spread around the nervous roots; if this is not apparent, move the needle to optimize diffusion. The fascia with its elastic structure acts as an envelope and will ensure anesthetic spread around the nervous fibers, which will provide motor and sensitive block within a few minutes.

Piercing the fascia is also crucial for the continuous block, because the perineural catheter must advance along the nervous structures for 2–3 cm.

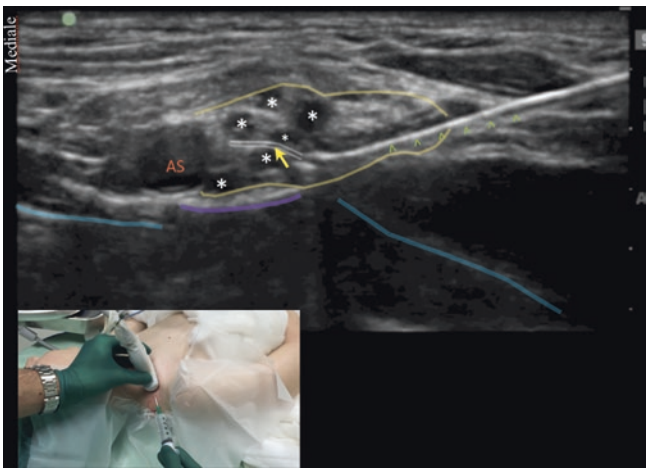


Fig. 32.1 In-plane supraclavicular approach for continuous nervous block: (*) nerve divisions; (^^^)Tuohy needle with perineural catheter coming out of needle tip (*yellow arrow*); the fascia (*yellow line*) that surrounds the brachial plexus is pierced by the needle; (AS) subclavian artery; pleura (*blue line*); first rib (*purple line*)

32.2 Continuous Infraclavicular Nerve Block

32.2.1 Surgical Indications

Besides anesthesia and postoperative anesthesia in elbow surgery, this block can be used for open and arthroscopic shoulder surgery (catheter tunneling has the purpose of keeping it away from the surgical field) and surgery of the humerus, forearm, and wrist (Borghi et al. 2004; Jankovic et al. 2006).

32.2.2 Therapeutic Indications

Continuous infraclavicular nerve block can be used for postoperative analgesia and/or rehabilitation of elbow, humerus, forearm and wrist.

32.2.3 Patient Positioning

Patient supine, arm abducted at 90°, forearm flexed at a 90° angle on arm when possible (Figs. 32.2, 32.3, and 32.4).

32.2.4 Anatomical Landmarks

Use the thumb to identify the deltoid-pectoral fossa by sliding in a medial to lateral direction along the inferior margin of the clavicle maintaining the nail parallel to the clavicle. The insertion point lies approximately 1.5 cm beneath the clavicle and at 1.5 cm from the deltoid-pectoral fossa (Figs. 32.2 and 32.3). At this point, the needle must be inserted vertically with a slight inclination toward the Chassaignac tubercle (transverse process of C_6), so that the catheter can later be directed proximally in the brachial plexus perineural fat (Figs. 32.2 and 32.3).



Fig. 32.2 Supine patient, arm abducted at 90°, forearm flexed at a 90° angle on arm. Local anesthesia with 1 mL levobupivacaine 0.5% has already been performed where the blood drop can be seen



Fig. 32.3 After identifying a biceps twitch at <0.4 mA, levobupivacaine 0.5% 20 mL is injected



Fig. 32.4 After removing the stylet, the catheter is advanced over the cannula. The cannula is then removed and the catheter is secured with a Lockit device, with part of the adhesive surface cut off

32.2.5 Technique

After determining the needle placing point, skin is adequately disinfected, and a transparent sterile drape with adhesive opening (e.g., Steri-Drape 3M Health Care) is positioned (Fig. 32.2). Local anesthesia of skin and subcutaneous tissue around the needle insertion point is performed (Fig. 32.2).

Afterward a needle with a cannula-over-needle system (e.g., Contiplex D, 15°bevel, 1.3 × 55 mm cannula, B Braun Melsungen) isolated and connected to a peripheral nerve stimulator (2 Hz; 1.5 mA) is inserted.

It is possible to improve the stability and duration of the fixing system by using the "PinPad" included in the needles from B Braun, cut and placed around the Lockit where it has been cut. The PinPad is far more adhesive than the Lockit.

I personally find the cannula-over-needle kit handier: if muscle twitch persists at <0.2 mA, it's sufficient to hold the cannula still and slightly withdraw the needle; it is also easier to give the catheter the desired direction this way.

For optimal anesthesia and analgesia of the elbow, shoulder, humerus, and forearm, the biceps and pronator muscles twitch (lateral cord) is sought.

For anesthesia and analgesia of the wrist and distal forearm, on the other hand, it is better to elicit a twitch of the flexor carpi muscles (medial cord).

The catheter must be advanced for about 3 cm, possibly in a rostral direction along the plexus, so that the max-

imum antalgic efficacy is obtained. This allows us to obtain the same effect of a supraclavicular block in a retrograde fashion, without the risk of pneumothorax associated with this approach when used without ultrasound guidance.

Once the desired twitch is elicited, the current intensity is lowered while adjusting with micro-movements the needle position, so that the twitch is still present at 0.3 mA.

32.2.6 Avoid

The following mistakes must absolutely be avoided, to lower the risk of pneumothorax in the lean patient:

- Do not advance the needle beyond 5 cm depth.
- Do not direct the needle medially toward the rib cage, if the needle is longer than 5 cm.

32.2.7 Integration of Supraclavicular or Infraclavicular Block with Axillary Approach

In case of incomplete supraclavicular or infraclavicular block, or to accelerate the onset, it may be useful to top up the block with an axillary approach, especially for the ulnar nerve (Jankovic et al. 2006).

Securing the catheter:

- Mount a fixing system (such as Lockit 16 o 18G, SIMS Portex) on the catheter, without removing the protection on the adhesive side, and connect the filter to the catheter, to maintain the tip sterile during the subsequent maneuvers.
- Accurately clean the skin with chlorhexidine or Amuchina, and then ensure that the skin around the catheter is dry.
- Hold the Lockit with the thumb, index, and middle finger.
- Remove the protection on the adhesive side and fix the Lockit to the skin, carefully avoiding catheter kinking.
- Use PinPad fragments attached to the sides of the Lockit to strengthen the system and lower the chance of accidental dislocation (Fig. 32.4).
- Cover the Lockit with a gauze of adequate size, humidified with disinfectant (chlorhexidine or Amuchina), and fix with light compressive dressing (e.g., Mefix). The gauze must completely cover the Lockit to avoid accidental removal of the Lockit and catheter with removal of the dressing (Fig. 32.5).

Examples of possible continuous local anesthetic infusion regimens for postoperative analgesia are given below:

0.2–0,4% ropivacaine or 0.125–0.25% levobupivacaine in elastomeric pump at 5/7/12 mL/h or in patient-controlled regional analgesia (PCRA) with basal infusion 5 mL/h, 3 to 5 mL on demand bolus, 10 min lock out. If PCRA pumps are not available, extra boluses may be administered by caregiving nurses via the three-way stopcock placed between the elastomeric pump and the catheter filter (Fig. 32.5).

In this case larger volume boluses, administered at longer intervals, can be employed to reduce the workload for the nursing personnel. To reduce the risk of accidental perineural administration of intravenous drugs, we suggest to use different color code screwcaps and to add a colored "nerve block" label besides the three-way stopcock (Figs. 32.4 and 32.5).

At the patient home, the PCRA can be continued with an elastomeric 250 mL pump set at 5–7–12 mL/h: the patient can modulate the infusion rate and stop the infusion by closing the three-way stopcock, connected to a 25 cm infusion tube. If needed, the pain control regimen can be integrated with oral nonsteroidal anti-inflammatory drugs such as ketoprofen or with minor opioids such as tramadol. Proper functioning of the infusion system must be verified before patient discharge.



Fig. 32.5 Light compressive dressing with sterile gauze humidified in chlorhexidine, placed so that the Lockit system is entirely covered and fixed with plaster such as Mefix. After surgery. the filter is connected to an elastomeric pump with a three-way stopcock

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Part III

Elbow in Sports

The Elbow of the Biker

33

Carlo Alberto Augusti and Giuseppe Porcellini

Motorcycling is a very popular sport on a professional and amateur level.

Despite the evolution of the personal protective equipment, a fall from the bike often leads to serious injuries, because the pilot's body is projected against the ground or fixed obstacles without the vehicle protection.

However, traumas are not the only injuries to which pilots are exposed. Motorcyclists are subjected to very intense stress due to the weight of the bike and of their body, to the forces produced by sudden changes of direction and posture, and to important vibrations transmitted from the engine and from the ground, both in training and during competitive race. These stresses can lead to overload syndromes in the upper limbs, the trunk, and, to a lesser extent, in the lower limbs.

In this chapter, a particular overload disease that especially affects the professional drivers will be treated, the chronic exertional compartment syndrome of the forearm.

33.1 Epidemiology

Chronic exertional compartment syndrome (CECS) is reported to occur in 14–27% of patients with undiagnosed exertional leg pain (Qvarfordt et al. 1983; Shah et al. 2004).

In the athlete's population, the incidence is reported to range between 10 and 60% (Lecocq et al. 2004; Qvarfordt et al. 1983). CECS may be observed in weight lifters and body builders, climbers, bikers (road, enduro, and motocross riders), practitioners of canoeing and kayaking, and sometimes baseball players (pitchers) (Bird and Mccoy 1983; Goubier and Saillant 2003).

In all these sports, athletes are exposed to repeated and intense stress on the forearm. In particular, motorcyclists are subjected to repeated stress bilaterally, even if the right arm is more exposed due to the use of the throttle (Allen and Barnes 1989). However, an interesting study on the physical characteristics of motocross riders (Gobbi et al. 2005) showed that these athletes develop more upper limb strength on the left arm (non-dominant), probably due to the increased use of the clutch.

33.2 Physiopathology

The most conventional theory was postulated by Martens and Moeyersoons (Martens and Moeyersoons 1990): a non-compliant fascia produces a stiff compartment that does not accommodate the increase in blood and muscle volume that occurs during exercise. Confirmations of both decreased blood muscle flow during exercise and increased fascia thickness in chronic exertional compartment syndrome cases can be either the cause or the effect of the elevated pressures measured in muscle compartments (Detmer et al. 1985; Qvarfordt et al. 1982).

33.3 Diagnosis

The diagnosis of CECS in the upper extremities is more difficult than in the lower limbs, and often treatment results are inappropriate due to the heterogeneity of symptoms.

Clinical history and examination are essential in the diagnosis of chronic compartment syndrome. Patients usually report pain and muscle hardening, with the inability to perform repetitive exercise. Symptoms subside when the offending activity is stopped but return when the activity is resumed. More severe cases can be associated with neurological symptoms such as tingling, numbness, and exercise-induced clumsiness in the limb. The physical examination at rest is typically normal.

When the history is indicative of chronic compartment syndrome, but symptoms are nondiagnostic, it is useful to determine whether pre- and postexercise pressures fall within normal limits.

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Different procedures have been described to confirm the diagnosis of CECS:

33.3.1 Intracompartmental Pressure Measurement (ICPm)

This method is considered the gold standard for the diagnosis of CECS with a sensitivity and specificity of 93% and 74% (Verleisdonk 2000).

A pressure tonometer is connected to a needle which is inserted in the examined compartment. According to the criteria postulated by Pedowitz et al. (1990), pressure measurements are taken prior to exercise and 1 and 5 mins after activity. There is a positive diagnosis of compartment syndrome at a rest pressure of more than 15 mmHg and/or 30 mmHg 1 min after exercise and/or 20 mmHg 5 min after exercise.

An interesting study evaluated normal extensor and flexor compartment pressures of the forearm (Ardolino et al. 2010). Normal forearm pressures pre- and postexercise ranged between 0 and 25.3 mm Hg for the extensor compartment and between 0 and 21.4 mm Hg for the flexor compartment. The authors suggest that in presence of typical CECS symptoms and raised pressures, the diagnosis should be confirmed. If atypical symptoms are present, a high pressure could aid the decision to proceed with surgical treatment.

33.3.2 Magnetic Resonance (MRI)

The MRI can be considered a noninvasive alternative to hydrostatic pressure measurements in an initial screening process for athletes with CECS symptoms in the forearm (Gielen et al. 2009). The diagnosis may be suspected if there is presence of edema (increased T2-weighted signal) in the flexor digitorum superficialis and flexor digitorum profundus after exercise. Preoperative hydrostatic pressure measurement is always recommended to confirm or exclude the diagnosis of CESC.

33.3.3 Near-Infrared Spectroscopy

With near-infrared spectroscopy (NIRS), it is possible to measure the hemoglobin saturation of tissues in a noninvasive manner with a sensitivity clinically equivalent to ICPm (van den Brand et al. 2005). Ischemia causes an increased extraction of oxygen by muscular tissue and therefore a decrease in venous oxyhemoglobin. Because more than 80% of the blood in tissue is in the venous compartment, tissue oxygen saturation (StO2) reflects more or less the venous saturation and therefore the level of local ischemia. Different studies have shown that patients with typical symptoms and elevated ICPs show a larger decrease in StO2 after exercise than do those without pressure elevation or healthy controls (Breit et al. 1997; Mohler et al. 1997; van den Brand et al. 2004).

33.3.4 Ultrasound

Ultrasound has been described as a useful procedure to detect CECS in the lower limb (Rajasekaran et al. 2013). The thickness of the anterior compartment is measured before and after exertion. In two studies, ultrasound hasn't shown significant different findings between patients with CECS and control subjects, especially after eccentric exercise (Birtles et al. 2002, 2003). The usefulness of this method in the diagnosis of CECS is still subject of debate.

33.4 Treatment

The proper treatment of CECS is surgical, especially in professional athletes.

Conservative treatment consists of deep massages and stretching before exercise. Unfortunately this type of prevention doesn't solve the problem and usually only delays the onset of symptoms during stress activity. The only conservative treatment that is certain to resolve this clinical condition is cessation of the activity that causes the symptoms. In the case of professional athletes, this corresponds to the cessation of their sport, and this solution cannot be taken into consideration.

The forearm is divided by the deep fascia into three compartments: the volar compartment (superficial and deep flexor compartments), the lateral compartment, and dorsal extensor compartment. The surgical treatment should decompress all the compartments with the less invasive approach.

Various fasciotomy techniques are described for the treatment of chronic exertional compartment syndrome of the

forearm. Different studies in literature have shown no statistical differences in outcomes of fasciectomy with or without fasciotomy (Slimmon et al. 2002; Slimmon et al. 2002; Winkes et al. 2012).

Fasciotomy can be performed with a volar or dorsal approach in order to decompress the flexor or extensor compartment (Harrison et al. 2013). In literature endoscopic approaches for fasciotomy of the forearm are also described (Jans et al. 2015; Pozzi et al. 2014). These techniques allow a minimally invasive approach to the forearm fascia, reducing the risk of recurrence due to fibrotic scar tissue formation and infections.

Author's preferred technique is a tri-compartmental fasciotomy performed with a posterior mini-open approach.

With the patient supine, the arm is elevated and adducted with the elbow at 90 degrees of flexion. The tourniquet is not used, and an accurate hemostasis is performed during and after the procedure.

A posterior skin incision of 5 cm is performed, centered on the ulna and 2–3 cm distal to the olecranon (Fig. 33.1). The subcutaneous fascia is "blindly" incised in distal direction medially and laterally (Fig. 33.2a, b). The epitrochlear muscles medially and the anconeus and epicondylar muscles laterally are gently detached from the bone till the ulnar crest. Once the compartments have been decompressed, skin closure is performed and a compression bandage is applied.



Fig. 33.1 Surgical approach for tri-compartmental fasciotomy of the forearm. Dashed lines represent the direction of the fascial incisions

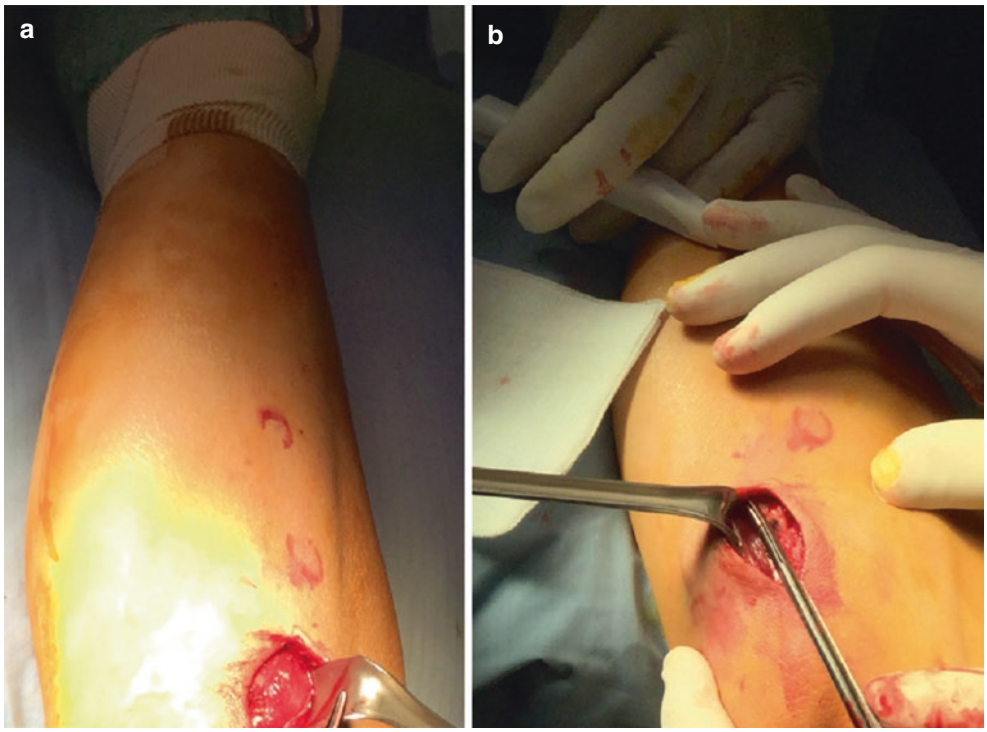


Fig. 33.2 Lateral fasciotomy (**a**). Medial fasciotomy (**b**)

33.5 Postoperative Care

Patients are allowed to passive movement of the wrist and elbow till the first day after surgery. Progressive muscular stretching and active exercises with full range of movement are started at 2 weeks after surgery.

33.6 Complications

Complications after forearm fasciotomy for the treatment of CECS are unfrequent. Subcutaneous hematoma can be observed after surgery, and it must be drained through the operative incision. Compression bandage and elevation of the limb after surgery help to avoid this complication.

Infections or peripheral nerve injury is rare.

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The Throwing Elbow

34

Andrea Pellegrini, Filippo Calderazzi, Enricomaria Lunini, and Pietro Tonino

34.1 Introduction

The specific constellation of elbow injuries suffered in baseball and other overhead sports, such as softball, football, tennis, and javelin, is well documented. These injuries include valgus extension overload syndrome (VEOS) with ulnar collateral ligament (UCL) tears, olecranon osteophytes, osteochondritis dissecans (OCD) of the capitellum, and loose bodies. Undoubtedly, the most frequent site of thrower's elbow injuries is the UCL.

The valgus and extension forces across the elbow during throwing activities often exceed the failure strength of the UCL. Repetitive or excessive stress leads to microtrauma and potentially acute rupture of the ligament. There is a cumulative effect of this microtrauma, and athletes who do not take adequate time to heal are at increased risk for rupture (Lyman et al. 2002). Over time, chronic medial tensile forces, lateral compressive forces and posterior compressive and shear forces lead to pathological changes and subsequent injury. These extreme medial and lateral forces can cause damages that can jeopardize the career of the throwing athlete (Kancherla et al. 2014). UCL tears are seen in tennis players, football players, wrestlers, javelin throwers, and, most commonly, baseball players, especially pitchers. Risk factors for UCL injury in baseball players include high-pitch velocity, inadequate warm-ups, and inadequate rest time (Petty et al. 2004). Chronic attenuation of the UCL can lead to further injury in the elbow due to increased bony stress, including radiocapitellar arthritis and posteromedial olecranon arthritis (Kancherla et al. 2014).

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UCL disruptions are commonly seen in conjunction with other injuries of the elbow, such as ulnar neuritis, medial epicondyle apophysitis, and flexor-pronator mass tendonitis. On the other hand, as these disorders can arise independently from UCL tears, they should remain in the clinician's differential diagnosis.

34.2 UCL Disruptions

34.2.1 Functional Anatomy

The bony anatomy of the proximal ulna and olecranon fossa provides primary stability at opposite ends of terminal motion: less than 20° and greater than 120° of flexion. The primary stability during the functional arc of an overhead athlete (20–120°) emanates from the soft tissue restraints (Miller and Savoie 1994; Schwab et al. 1980; Morrey et al. 1991). The soft tissue structures that provide static valgus elbow stability vital to overhead throwing include the anterior joint capsule, the UCL complex, and the radial collateral ligament complex. Specifically, the primary soft tissue elbow stabilization source for the throwing athlete is provided by the UCL. At 90° of elbow flexion, the UCL accounts for 55% of the stabilizing resistance to valgus stress and 78% of the resistance to varus stress (Morrey and An 1983). The UCL is composed of three distinct parts: the anterior bundle, the posterior bundle, and the oblique bundle (transverse ligament). The anterior bundle originates from the inferior side of the medial epicondyle and inserts at the sublime tubercle on coronoid process medial side (Miller and Savoie 1994; Schwab et al. 1980; Morrey 1986; Jobe and Kvitne 1991; Sojbjerg et al. 1987). The anterior bundle is further divided into distinct anterior and posterior bands. The anterior band is the primary restraint for valgus strain for elbow flexion up to 90°, and the secondary restraint for further flexion. Conversely, the posterior band is an important restraint to valgus strain at flexion angles >60°, but is a secondary restraint at lesser angles (Chen et al. 2001, 2005; Callaway

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et al. 1997). When UCL injury occurs, the anterior bundle is most often involved as it is the primary restraint to the valgus stress experienced in the overhead thrower (Field and Savoie 1998). In cadaveric studies, the UCL has been directly measured to fail between 22.7 and 33 Nm, while 120 Nm of peak valgus torques have been measured at the medial elbow of experienced overhead throwers (Werner et al. 2002; Ahmad et al. 2003; Fleisig et al. 1999; Paletta et al. 2006). This discrepancy is explained by flexor-pronator musculature activation as a dynamic elbow joint stabilizer. The flexor-pronator musculature, which originates from the medial epicondyle and the distal medial epicondylar ridge of the humerus, helps to provide dynamic stability of the elbow against valgus stress (Miller and Savoie 1994; Chen et al. 2001, 2005; Callaway et al. 1997; Davidson et al. 1995).

The posterior bundle of the UCL is fan-shaped, extending from the medial epicondyle of the humerus to the medial margin of the semilunar notch of the ulna. Thinner and weaker than the anterior bundle, the posterior bundle provides secondary restraint to elbow valgus loads when elbow flexion is >90° (Schwab et al. 1980; Chen et al. 2001). The posterior bundle is thought to be vulnerable to valgus overload strain only if the anterior bundle has been completely transected (Chen et al. 2001; Callaway et al. 1997).

34.3 Biomechanics and Pathophysiology

The injury patterns of the thrower's elbow can be explained by one mechanism: valgus extension overload syndrome (VEOS) (Wilson et al. 1983). During overhead throwing, a large valgus force on the elbow created by humeral torque is countered by rapid elbow extension creating significant tensile stress along the medial compartment, shear stress in the posterior compartment, and compressive stress in the lateral compartment (Fleisig et al. 1995; Limpisvasti et al. 2007). Maximum valgus force across the elbow is generated during late cocking and acceleration (Fleisig et al. 1995). The elbow is flexed to 95° and the elbow, primarily the anterior bundle of the UCL, is subjected to valgus forces up to 64 Nm (Glousman et al. 1992; Davidson et al. 1995) (Fig. 34.1). Indeed, as the elbow moves into 95° of flexion, the medial collateral ligament takes on 55% of the burden. The remainder of this stress is taken up by the strong flexor-pronator muscle mass on the medial side of the elbow (Kancherla et al. 2014). During acceleration, the elbow extends at more than 2300° per second (Fig. 34.2). At the time of ball release, the lateral aspect of the elbow (radiocapitellar joint) is subject to greater than 500 N of force. Repetitive, near-failure tensile stresses create microtrauma and attenuation anterior bundle of the UCL, leading to progressive valgus instability. Continued shear stress and impingement in the posterior compartment lead to olecranon tip osteophytes, loose bodies, and articular damage to the posteromedial trochlea in the continuum of VEOS (Martin and Baumgarten 1996; Cain et al. 2003). Over the time, the shoulder undergoes adaptative changes: they include increase of external rotation from humeral retroversion and capsular laxity as well as decrease in internal rotation (glenohumeral internal rotation deficit—GIRD). Burkhart and colleagues proposed that increased humeral torsion leads to greater external rotation of the shoulder during late cocking, thus providing a longer throwing arc and potentially a greater peak velocity that increases the stresses experienced by the elbow (Burkhart et al. 2003).



Fig. 34.1 Late cocking phase



Fig. 34.2 Acceleration phase

In a study of 29 baseball players, GIRD is encountered in athletes with UCL insufficiency, with an average deficit of 28.5°(Dines et al. 2009).

As the UCL becomes incompetent, the osseous constraints of the posteromedial elbow become important stabilizers during throwing. Since it is difficult to make an early diagnose, the UCL also leads to stretch of the other medial structures, including the flexor-pronator mass and ulnar nerve. Extrinsic valgus stresses and intrinsic muscular contractions of the flexor-pronator mass lead to tendonitis. Concluding the spectrum of thrower's elbow lesions, ulnar neuropathy is often due to the superficial position of the nerve. The nerve can be injured by traction, compression and irritation at elbow medial side.

34.4 Risk Factors of VEOS

The majority of baseball elbow injuries are noncontact injuries of the dominant arm due to repetitive pitching (Fig. 34.3) (Collins and Comstock 2008; Lyman and Fleisig 2005; Fleisig and Andrews 2012). The amount of pitching is the risk factor which has the strongest correlation with this kind of injury (Olsen et al. 2006) and prospective studies have also identified overuse as the principle risk factor for pitching injury (Fleisig et al. 2011).

Besides, improper pitching mechanics can lead to increased elbow varus torque and consequently increased risk of elbow injury (Fortenbaugh et al. 2009).

Specific technique flaws associated with increased varus torque include hand under the ball during the stride phase (Davis et al. 2009), late arm rotation (measured as insufficient shoulder external rotation at the instant of front foot contact) (Fleisig 1994), excessive shoulder external rotation (Aguinaldo and Chambers 2009; Sabick 2004), excessive elbow flexion, and improper shoulder abduction and trunk tilt (Matsuo et al. 2006).

Correcting flaws in pitching mechanics can reduce the stress on the elbow, reduce the stress on the shoulder, and/or increase ball velocity. Improving biomechanics can increase a pitcher's chance of staying healthy and succeeding.

Another aspect to be considered is that youth baseball pitchers also play other positions. Even if a young player specializes as a pitcher, pitch count rules and inning limits have made it harder to pitch all of the time. The pitcher-catcher combination in particular has been suggested as a risk factor. Repetitive pitching may create microscopic tears in the elbow or shoulder that need rest to recover. The quantity of throws by a catcher may add to the cumulative load inhibiting recovery.

Other potential risk factors are physical conditioning, nutrition, hydration, and playing environment. Young children often have less coordination and skill than older players (Fleisig et al. 2009). The focus for young players should be to develop physical fitness, athleticism, knowledge of baseball, and enjoyment of the game. Strength and physical conditioning programs for younger players should be aimed at developing general fitness and athleticism, with concentration on functional strength for pitching added for the more advanced athletes. Nutrition and hydration are important for general health as well as for recovery from pitching (Beelen et al. 2010; Bonci 2009).

Outdoor temperature and humidity are also factors for player health and risk of injury (Beelen et al. 2010).



Fig. 34.3 Pitching

A potential risk factor for youth pitchers is physical maturity.

If children are bigger, faster, and stronger because they developed early physically, they are usually overrepresented in key sports positions such as baseball pitcher (Hirose 2009; Matthys et al. 2012).

Overuse may be particularly risky for early developers. Muscles of young athletes develop secondary to growth spurts. Strong muscles with open growth plates may increase the risk of physeal plate injuries in a young pitcher's elbow or shoulder (Kelly and Pappas 1997).

34.5 Clinical Presentation and Physical Examination

A thorough medical history begins with knowing the patient, his/her sport and level of competition. The patient often complains acute onset of medial elbow pain associated with a "pop" during overhead throwing activity, with inability to continue to throw or chronic medial elbow pain during the late cocking to early acceleration phases of the throw and a progressive loss in accuracy, endurance, and velocity (Hausman and Lang 2014). These athletes are frequently taller and heavier, although it is unclear if the risk of injury is related to increased strength of the athlete or a longer forearm lever that generates larger valgus forces on the elbow (Han et al. 2009). Chronic injury often presents with flexor-pronator tendinopathy with pain when gripping.

Patients in the later stages of chronic UCL injury may report pain with terminal extension of the elbow. Physical examination should begin with assessment of both passive and active ranges of motion. Any joint effusion or flexion contracture should be documented. The carrying angle of the elbow, normally 11° in men and 13° in women, may be as large as 15° in throwers as result of adaptive change secondary to the repetitive stress and laxity of the UCL (Regan et al. 1991). Moreover, it is not uncommon to assess an increased medial laxity in asymptomatic baseball pitchers (Nazarian et al. 2003; Ellenbecker et al. 1998). The elbow should be palpated to determine sites of abnormal tenderness.

Neurologic changes should be assessed, as laxity of the UCL can cause tension on the ulnar nerve, leading to complaints of weakness or paresthesias.

As first aforementioned, besides ulnar neuropathy, other associated pathologies of VEOS can lead to painful radiocapitellar overload, posterior compartment pain, and impinging osteophytes. Indeed, lateral pain with pronation and supination may indicate arthritic change due to overload of the lateral structures, whereas posterior discomfort in full extension suggests posteromedial olecranon arthritic change secondary to repetitive extension overload.

Diagnosis of GIRD in patients with UCL injuries has clinical importance because treating the shoulder pathology can prevent worsening of the UCL injury, and its presence alters the postoperative rehabilitation of UCL reconstruction (Hausman and Lang 2014). Multiple examination maneuvers aid in the diagnosis of UCL injury. In the valgus stress test, the examiner applies a valgus stress to the affected elbow, assessing for the lack of a firm endpoint or medial joint space opening. Examination is compared with the contralateral elbow. Traditionally, the test is done with the elbow at 20° to 30° of flexion to unlock the ulnohumeral joint and olecranon. However, a cadaveric study determined that the elbow is

most unstable when valgus stress is applied at 70° of elbow flexion (Sojbjerg et al. 1987). More recently, Safran et al. (2005), in another cadaveric study, determined that valgus laxity was greatest with the forearm in neutral position compared with pronation or supination. They found no difference when the elbow was at 30°, 50°, or 70° of flexion. Overall, the original valgus stress test has been found to be 66% sensitive and 60% specific for detecting injuries to the anterior band of the UCL. The milking maneuver tests the integrity of the posterior band of the anterior oblique portion of the UCL. With the forearm supinated and the shoulder extended, the elbow is flexed beyond 90, and a valgus stress is applied by pulling on the patient's thumb with the other hand. A positive result is suggested when the patient reports medial joint pain, apprehension, or instability. A modification to this test removes the shoulder as a confounding variable and places the elbow in a position of maximal valgus laxity (Hariri and Safran 2010; Sojbjerg et al. 1987). The patient's shoulder is adducted with maximal external rotation, and the patient's elbow is flexed at 70° while the examiner's hand supports the elbow using his or her thumb to palpate the medial joint space and detect any widening (Hariri and Safran 2010).

O'Driscoll et al. (2005) described the moving valgus stress test that was 100% sensitive and 75% specific for detecting UCL tears when compared with surgical exploration or arthroscopic examination with valgus. In this dynamic examination maneuver, the patient's shoulder is abducted and externally rotated as the examiner applies a constant moderate valgus torque to the flexed elbow and then quickly extends the elbow. Medial-sided elbow pain (from which the patient often withdraws) at the midarc of motion between 120° and 70° suggests a positive result. The mean angle with maximal pain is 90°. This dynamic test incorporates multiple stresses on the elbow in addition to valgus stress and more accurately mimics the stress on the UCL during overhead throwing, providing a more sensitive and specific test.

34.6 Imaging

Anteroposterior (AP), lateral, internal oblique, external oblique, and axial radiographs should be obtained. The examiner should assess for osteophytes, loose bodies, or calcification of the ligaments. In cases in which the diagnosis of UCL injury is in doubt, valgus stress views of the affected elbow in 25° of flexion should be compared with the contralateral elbow. Gapping of greater than 3 mm compared with the contralateral side indicates laxity of the UCL (Murthi et al. 2011; Emery 2006; Rijke et al. 1994).

Using stress radiography, Ellenbecker et al. (1998) measured the joint space width between the trochlea of the humerus and coronoid process of the ulna of 40 healthy professional baseball pitchers. Results showed increased medial elbow laxity in the dominant arm of uninjured pitchers compared to their nondominant arm. Ultrasound is an inexpensive and noninvasive imaging study to assess the UCL. Sonogram of an injured UCL will exhibit heterogeneity, thickening, and possibly calcifications.

Dynamic stress ultrasonography can be a useful adjunct when static ultrasound fails to yield the diagnosis (Nazarian et al. 2003; Sasaki et al. 2002). As with other forms of ultrasound imaging, ability to detect pathology is dependent on the skills and technique of the technician. Advanced imaging with magnetic resonance imaging (MRI) and computed tomography (CT) arthrogram may be necessary when the diagnosis of UCL injury is in doubt, as well as for preoperative planning. For partial tears, CT arthrogram is 86% sensitive and 91% specific. Magnetic resonance imaging (MRI) is also valuable in identifying athletes with UCL injury, as it has been shown to have 100% sensitivity and 100% specificity in identifying full-thickness tears (Tuite and Kijowski 2006; Timmerman et al. 1994; Murphy 1992). MRI is also 100% specific in identifying partial-thickness UCL tears, although it is much less sensitive (57%).

MR arthrogram remains the test of choice, having the highest interobserver reliability (Carrino et al. 2001) and the greatest ability to identify complete tears, with 86% sensitivity for partial tears, 95% for complete tears, and 100% specificity for both (Schwartz et al. 1995).

34.7 Conservative Treatment

Conservative treatment for medial elbow injuries associated with throwing generally has positive results (Gregory and Nyland 2013).

Among athletes with no radiographic or MRI evident changes, elbow and wrist muscle strengthening exercises may be beneficial, but the origin of the pain must be established. Athletes with VEOS or with findings consistent with a partial tear of the UCL should be initially placed on a period of active rest for 6–12 weeks (Patel et al. 2014) and strict rest from compressive forces is recommended (Roub et al. 1979; Matheson et al. 1987; McFarland et al. 2003). Two to eight weeks of rest coupled with judicious use of ice, massage and nonsteroidal anti-inflammatory medication and a supervised rehabilitation program focusing on restoring pain-free active elbow and wrist joint mobility, muscle strength, and endurance are indicated (Jobe et al. 1984). It is important to protect the elbow from valgus stress, including throwing, for a minimum of 6 weeks (Patel et al. 2014). Pain or anti-inflammatory medications should never be used merely to enable the symptomatic athlete to continue sports activities. Corticosteroid injections are avoided, as they may further damage elbow ligamentous and cartilaginous structures. After 3–6 months of treatment, if symptoms have

improved and the athlete has regained full range of motion and strength, a mediated throwing program may be initiated (Roub et al. 1979; Matheson et al. 1987). Most conservative treatment programs have shown full recovery rates of 40–50% in competitive overhead throwing athletes (Kooima et al. 2004).

A criteria-based return-to-throw program is initiated when functional patterns, with resistance, consistent for pitching are pain-free and valgus stress testing is negative. Rettig et al. (2001) evaluated 31 throwing athletes treated nonoperatively for a UCL injury with a minimum of 3 months of rest with rehabilitation. They reported a 42% return to competitive throwing at the same level or higher at an average of 24.5 weeks. In non-throwing athletes, results are better with full recovery in 100% of patients with UCL injuries treated conservatively (Crockett et al. 2002).

Unfortunately, no data are available as to which findings in the history or physical examination predict successful nonoperative treatment (Kancherla et al. 2014).

Platelet-rich plasma (PRP) injections have shown some promise by increasing return to play rate following partial UCL tears. PRP injection has been shown to improve disabilities of the arm, shoulder, and hand scores and decrease medial joint space gapping under stress while maintaining an 88% return to preinjury level of play (Podesta et al. 2013). Average time for return to play is 12 weeks after PRP injection. Additional studies are required to validate these results (Kancherla et al. 2014, Stachowicz et al. 2014).

34.8 Surgical Treatment

If conservative treatment fails, referral to an orthopedic surgeon is essential, as surgical intervention may be needed. There are several surgical techniques used to reconstruct the UCL. Overhead throwing athletes with complete disruption of the anterior bundle of the UCL are candidates for surgical intervention if they wish to return to preinjury level of play. Athletes with partial tears unable to return to competitive throwing (or other overhead sport) due to continued medial elbow pain despite completion of an adequate course of nonoperative treatment are considered candidates for surgical treatment as well. The goal of surgical reconstruction of the UCL is restoration of valgus stability to the elbow. Direct primary repair of the UCL is reserved for acute avulsion injuries from either the humeral origin or coronoid insertion (Jobe et al. 1986; Norwood et al. 1981; Conway et al. 1992). UCL injuries in throwing athletes are typically present, however, as attenuated ligaments or midsubstance tears. Chronic repetitive microtrauma leads to significant scarring and subsequent inability for effective primary repair of the UCL (Arendt 1999; Morrey and Regan 1994). Frank Jobe first performed reconstruction of the elbow UCL on September 25, 1974, on Los Angeles Dodgers left-handed pitcher Tommy John. John returned to pitching in 1976 and over the next 13 seasons went on to pitch 2500 innings, compiling a record of 164 wins and 125 loses and never having another significant problem with his elbow. John's successful return to pitching after surgery revolutionized the treatment of athletes with injuries to the UCL and popularized the procedure, known as Tommy John surgery.

In the Jobe 3-ply technique, the ipsilateral palmaris longus tendon is harvested as a graft (Fig. 34.4a–c) (Jobe et al. 1986; Conway et al. 1992). Two converging drillings are carried out in the sublime tubercle of the proximal ulna, creating a bone tunnel (Fig. 34.5a, b), and two divergent drill holes are created in the medial epicondyle (Fig. 34.6a, b). With the assistance of a suture passer, the graft is passed first through the bone tunnel in the ulna (Fig. 34.7). It is then crossed over itself as the posterior end of the graft is passed up the anterior tunnel into the medial epicondyle with the anterior end going into the posterior tunnel (Fig. 34.8). The end within the posterior tunnel is then brought up around the back of the epicondyle and passed distally back into the anterior tunnel, exiting at the entrance point into the medial epicondyle (Fig. 34.9). With the elbow positioned in approximately 30° of flexion and the forearm in neutral rotation, with a slight varus moment applied to the elbow, the graft is tensioned and sutured to itself, resulting in a 3-ply graft reconstruction (Fig. 34.10). Any remaining native ligament is then incorporated into the graft, reinforcing the construct. The classic Jobe surgical technique involves exposing the UCL by reflecting the flexor-

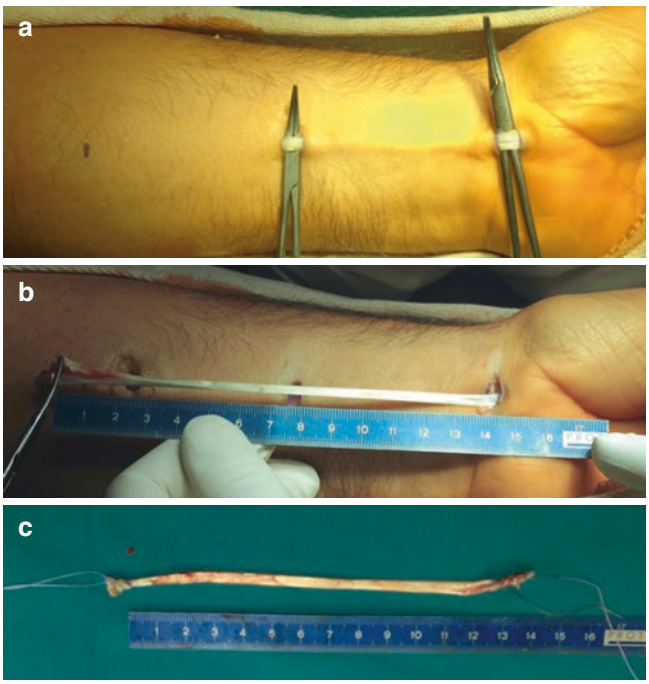


Fig. 34.4 (**a**) Harvesting (**b**) measurement (**c**) and stitching of ipsilateral palmaris longus tendon as a graft

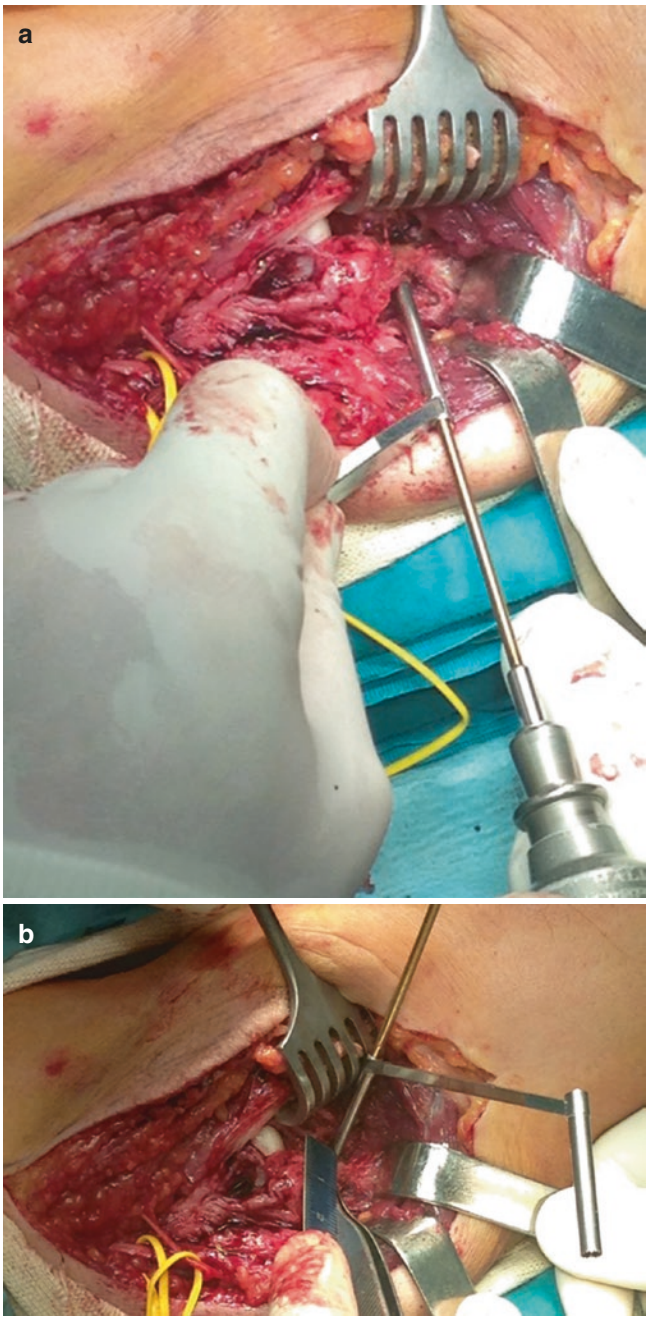


Fig. 34.5 (**a**, **b**) Drilling of two converging holes into the sublime tubercle of proximal ulnar, so creating a bone tunnel

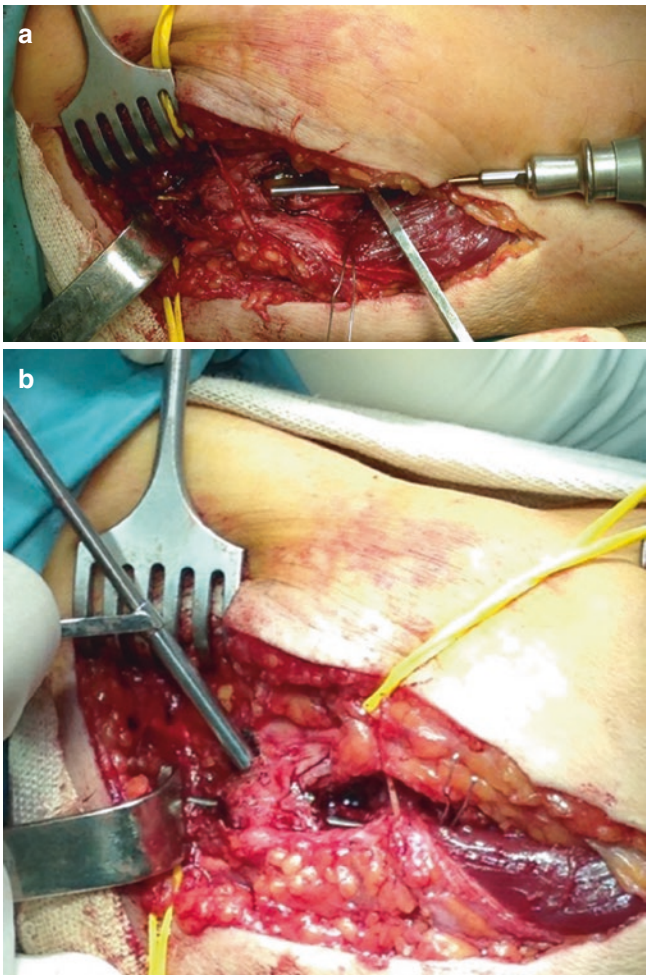


Fig. 34.6 (**a**, **b**) Creation of two divergent drill holes in the medial epicondyle

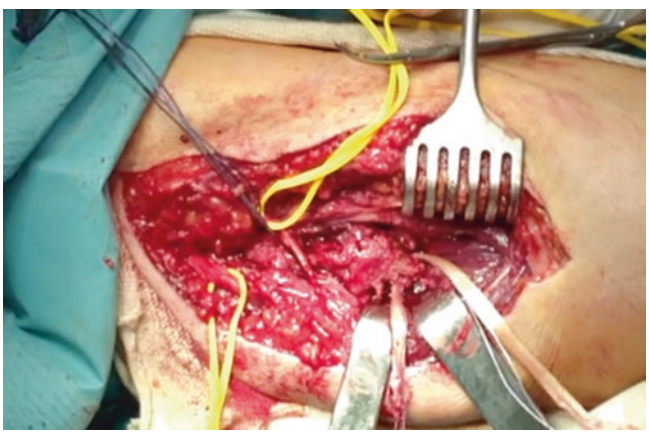


Fig. 34.7 Passage of the graft through the bone tunnel in the ulna

pronator origin off the medial epicondyle and anteriorly transposing the ulnar nerve in a submuscular position. Early published results of UCL reconstructions performed using this technique reported a high incidence of postoperative ulnar nerve complications (Jobe et al. 1986; Conway et al. 1992). Overall, Jobe documented 63% return to play and a complication rate of 31% (Jobe et al. 1986).

Conway et al. (1992) described 71 baseball players with UCL insufficiency (70% professional), 56 of whom were treated with UCL reconstruction. They used similar technique as Jobe et al. (1986) and 68% returned to play.

In an effort to minimize ulnar nerve complications, contemporary techniques use a muscle-splitting approach

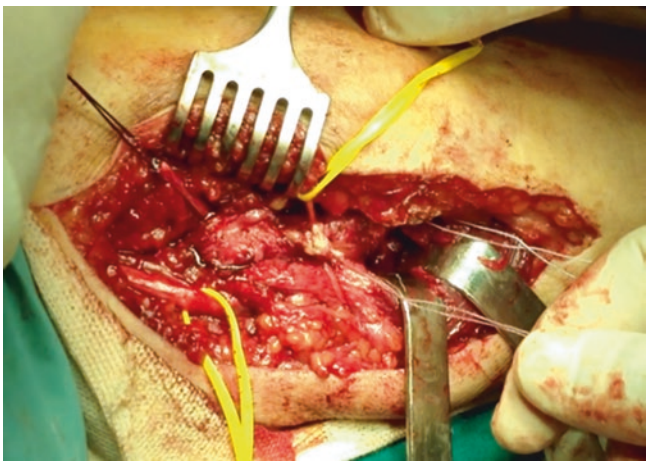


Fig. 34.8 The graft is crossed and passed into the divergent tunnels of the medial epicondyle

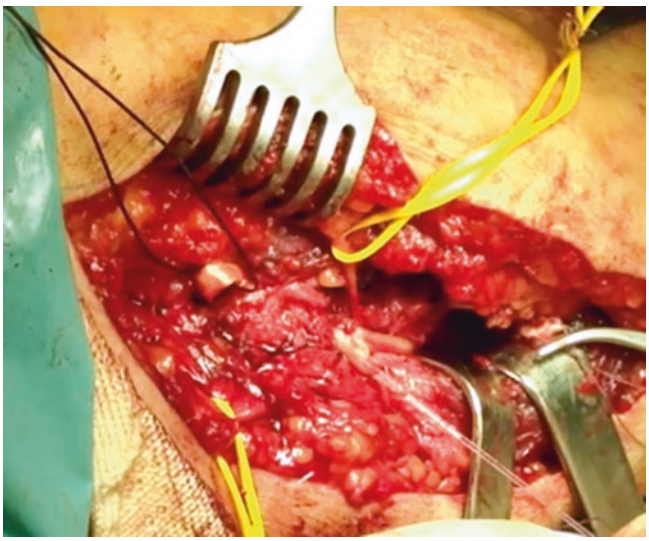


Fig. 34.9 The end of the graft within the posterior tunnel is brought up around the back of the epicondyle and passed distally back into the anterior tunnel

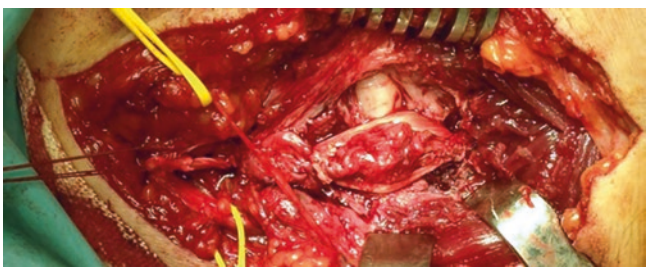


Fig. 34.10 The graft is tensioned and sutured to itself with the elbow at 30° of flexion, the forearm in neutral rotation and a slight varus moment applied

through the FCU (flexor carpi ulnaris), introduced by Smith et al. in 1996 (Smith et al. 1996; Thompson et al. 2001a, b).

Several modifications of the Jobe original 3-ply technique have been developed over the past decade (Langer et al. 2006). In addition, a variety of graft fixation methods have been investigated in both the clinical and laboratory settings. These include interference screws, suture anchors, flip buttons (Endobutton™), and combinations of these fixation methods, along with variations in tunnel placement both proximally and distally (Langer et al. 2006; Armstrong et al. 2005; Ahmad et al. 2003; Ciccotti et al. 2009; Dodson et al. 2006; Hurbanek et al. 2009; Large et al. 2007; McAdams et al. 2007; Morgan et al. 2010; Nissen 2008; Paletta et al. 2006; Shah et al. 2009; Rohrbough et al. 2002; Starman et al. 2010).

In the mid-1990s, suture anchors were introduced in an attempt to further simplify UCL reconstruction. However, this technique was reportedly terminated when clinical application yielded a failure rate of 30% (Williams et al. 2004). Yet it determined that graft tension and placement within the bony tunnel are the key determinants of a successful reconstruction.

The most widely applied and studied among the newer reconstruction techniques is the docking procedure (Smith et al. 1996; Armstrong et al. 2005; Ciccotti et al. 2009; Dodson et al. 2006; Paletta et al. 2006; Rohrbough et al. 2002; Bowers et al. 2010; Koh et al. 2006).

In 1996, Smith et al. (1996) first developed the docking procedure, the results of which were reported by Rohrbough et al. (2002) in 2002 and Dodson et al. (2006) in 2006. They showed 92% and 90% excellent results, respectively, without ulnar nerve transposition and a muscle-splitting approach.

The docking technique modifies the Jobe technique further, simplifying graft passage, tensioning, and fixation. The initial approach to the ulna closely parallels the Jobe technique. The flexor-pronator mass is split and elevated from the UCL, and the ulnar tunnel is made in the fashion described above. The humeral tunnel position is located in the anterior half of the medial epicondyle at the anatomic insertion of the native UCL, similar to the Jobe technique. This tunnel is created to a depth of 15 mm using a 4-mm burr or drill. The upper border of the epicondyle is exposed by excising the fascia there. Two small exit tunnels separated by a bone bridge of 5 mm to 1 cm are created, stemming from the 4-mm primary humeral tunnel. Suture loops are then placed with a straight needle from the primary humeral tunnel through the exit tunnels to facilitate graft passage. With the elbow in forearm supination and mild varus stress, the horizontal incision in the native UCL is repaired with a No. 2.0 absorbable suture. The graft is then passed through the ulnar tunnel from anterior to posterior. The posterior limb of the graft is passed into the humeral tunnel and secured. The final length of the anterior limb of the graft is determined by placing it adjacent to the humeral tunnel and visually estimating the length of the graft needed to provide adequate tension once secured in the humeral tunnel. A No. 1 braided nonabsorbable suture is placed in a Krakow fashion on the end of the anterior limb of the graft. The excess graft is excised, and

the graft limb is passed into the humeral tunnel with the sutures exiting the small tunnels. Final graft tensioning is performed by ranging the elbow through full flexion, extension, supination, and pronation, with varus stress placed on the elbow. With the elbow in 60° of flexion and full supination, and with varus stress applied, the sutures are then tied over the bony bridge on the humeral epicondyle. This method of fixation eliminates the suture/graft interface that is present in the 3-ply reconstruction and has been shown in biomechanical studies to have higher peak load to failure values compared with Jobe technique (Armstrong et al. 2005; Paletta et al. 2006).

Dines et al. (2012) reported on ten javelin throwers and showed 90% return to play at the same or higher level of competition after UCL reconstruction using the docking procedure.

A modification of the docking technique has recently been introduced. The DANE TJ UCL reconstruction uses traditional docking fixation proximally into a socket within the medial epicondyle of the humerus (Dines et al. 2007; Nissen 2008). Distally, however, instead of a tunnel in the ulna, another socket is created. Fixation of the ulnar end of the graft is achieved with an interference screw, whereas fixation proximally is performed with two sutures exiting the end of the humeral socket and tied to each other, as in the traditional docking technique.

This technique has several advantages. First, it is less technically demanding because fewer drill holes are required. Second, the muscle-splitting approach used requires less dissection because only a single central ulnar tunnel is required, rather than two tunnels with an intervening bony bridge. Third, because there is no need to make a posterior ulnar tunnel, which often exits close to the ulnar nerve, morbidity to the nerve is minimized. Finally, graft passage is less difficult with an interference screw in a single tunnel. In situations in which the sublime tubercle is insufficient, such as in the case of previous fracture or prior reconstruction, the hybrid interference screw technique may be preferable.

To augment proximal fixation of the graft, some surgeons place an interference screw within the medial epicondyle socket. The addition of an interference screw for fixation proximally has been shown to result in less gap formation under valgus loading in the laboratory setting, perhaps allowing for better healing of the graft within the humeral bone socket (Hurbanek et al. 2009; McAdams et al. 2007). Aperture fixation, as is achieved with interference screws, may also result in increased graft isometry and increased stiffness of the overall construct (Ahmad et al. 2003).

Concerns with this type of fixation include low initial fixation strength and the potential for graft slippage in the early postoperative period (Hurbanek et al. 2009).

Another effective UCL reconstruction technique is the double-bundle procedure using an Endobutton as distal fixation device.

The sites of attachment of the UCL are located on the humerus and the ulna. Bone tunnels are created in the proximal ulna and medial epicondyle of the humerus using a motorized drill and a drill guide. Ulnar tunnels are made anterior and posterior to the sublime tubercle by using a 3-mm drill to create a 2-cm bridge. The tunnels are connected using a small, curved curette. The humeral tunnel position is located in the anterior half of the medial epicondyle. A longitudinal tunnel is created up the axis of the medial epicondyle to a depth of 15 mm by using a 4-mm drill. With the use of a dental drill with a small bit, two small exit punctures separated by 5 mm to 1 cm are created to allow suture passage from the primary humeral tunnel. Arthrex FiberWire #5 is then passed through the ulna from anterior to posterior. One end of the FiberWire is passed into the humeral tunnel and one of the small superior humeral punctures. With this first limb securely docked in the humerus, the second half of the FiberWire is visually measured to estimate the length needed for tensioning the other limb. This end of the graft is docked securely in the humeral tunnel exiting the small puncture holes. Once the surgeon is satisfied with the FiberWire tensioning, both sets are tied over the bony bridge on the humeral epicondyle with an Endobutton.

34.9 Surgical Considerations

Biomechanical studies of UCL reconstruction techniques show that all ligament reconstruction techniques are inferior to the native UCL (Nassab and Schickendantz 2006). UCL reconstruction requires a tendon graft which is usually the palmaris longus. Typically 15–17 cm is needed.

Biomechanical studies have shown that the palmaris has a higher ultimate failure load (357 N) than that of the anterior bundle of UCL (260 N).

The palmaris longus is the most commonly used graft choice. However all surgical candidates should be assessed for the presence of the palmaris longus because it is absent in up to 25% of the population (Thompson et al. 2001a, b).

Other suitable options for graft material include the contralateral palmaris longus tendon and gracilis tendon. Allograft gracilis tendon may also be used. Savoie et al. (2013) performed hamstring allograft UCL reconstruction in 116 overhead athletes. Of these 116 athletes, 110 returned to play with 88% playing at or above preinjury level.

Complication rates are reportedly less than 10%. The ulnar nerve should be assessed prior to surgery. Ulnar neuritis commonly presents concurrently with UCL tears. In addition, ulnar nerve subluxation may occasionally also be present. In early reports of UCL reconstruction, the ulnar nerve was routinely transposed (Jobe et al. 1986; Conway et al. 1992). More recent technique modifications, in particular splitting the flexor-pronator origin instead of taking it

down, have obviated the need for nerve transposition unless specific criteria are met (Langer et al. 2006).

If the patient reports symptoms of ulnar neuritis (pain, numbness along the fourth and fifth digits) and nerve subluxation preoperatively, ulnar nerve transposition is indicated.

Symptoms of ulnar neuritis and ulnar motor deficits also are an indication for transposition. Subcutaneous transposition appears to have fewer complications than submuscular transposition (Azar et al. 2000).

Biomechanical studies have shown that UCL reconstructions are inferior to the native UCL complex.

Hechtman et al. compared the biomechanical properties of the native UCL complex with both the Jobe technique and a less invasive reconstruction procedure that replaced the traditional bone tunnels with bone anchors. Elbow specimens were loaded to failure in a materials testing machine at a fixed angle of 30°. The results of this study indicated that the bone anchors were better able to mimic the strain patterns of both anterior and posterior bundle of UCL during flexion and extension. However, the intact ligament was still significantly stronger than either reconstruction (Hechtman et al. 1998).

As aforementioned, a novel interference screw technique designed to minimize soft tissue dissection, injury to the ulnar nerve, and ease of fixation was researched by Ahmad et al. (2003) Intact, disrupted, and reconstructed ligaments were tested both kinematically and to failure. This technique, though significantly inferior in overall stiffness to the native UCL, was able to nearly replicate the ultimate moment and valgus stability of the native complex. This study did not incorporate cyclic loading which would assess the fixation characteristics during the early postoperative course.

Armstrong et al. (2005) compared the initial strength of the Jobe, docking, Endobutton, and interference screw UCL reconstruction techniques with each other and the native complex. The respective reconstructions were cyclically loaded to failure in a stepwise manner. The initial strength and mean displacement of the graft at varying loads was significantly lower than the native UCL complex.

The biomechanical parameters of the Jobe and docking techniques with an increased graft surface area were analyzed by Paletta et al. (2006) Elbows were potted and tested using a servohydraulic materials testing machine to apply a valgus moment at 30°of elbow flexion. Both the native ligament and the docking construct showed similar values for maximal moment to failure. However, the native ligament complex exhibited a substantially better biomechanical profile than either reconstruction technique. More specifically, the native complex exhibited a higher stiffness and lower strain at maximal moment.

McAdams et al. (2007) evaluated the effect of cyclic valgus loading on the docking and bioabsorbable interference screw techniques. A cyclic valgus load was applied to elbows and the valgus angle was measured at varying cycles. The bioabsorbable interference screw technique resulted in a smaller valgus angle widening as compared with the docking technique.

A recent systematic review by Watson et al. (2014) found that the docking technique and a suspensory button technique most commonly failed secondary to suture failure, whereas the most common modes of failure for the Jobe technique and interference screw technique were ulnar tunnel fractures and graft ruptures, respectively.

Generally, there is no clear biomechanical superiority of one reconstruction technique over the other.

The arthroscopic valgus stress test may have some utility in assessing the competence of the UCL prior to reconstruction. In this test, the ulnohumeral joint is stressed in valgus with the forearm maximally pronated and the elbow at 90° of flexion. The ulnohumeral opening is <1 mm in most normal elbows, although this is a purely subjective observational measurement. Furthermore, a cadaveric study concluded that the anterior bundle of the UCL could not be visualized arthroscopically (Field et al. 1995). Preoperative elbow arthroscopy seems to have more of an adjunctive diagnostic utility. Posteromedial decompression should be considered very carefully. It should not be undertaken if the patient does not have posteromedial elbow pain in extension. In addition, isolated posteromedial debridement should not be done if UCL insufficiency is present. As noted earlier, UCL resection increases valgus angulation and strain on the UCL during valgus stress. UCL insufficiency may also lead to increased posteromedial wear and subsequent osteophytes, which may result in an artificially stable joint. Therefore, isolated posteromedial decompression may render symptomatic previously asymptomatic UCL insufficiency. One series reported UCL insufficiency requiring reconstruction after isolated posteromedial decompression (Andrews and Timmerman 1995).

Azar et al. (2000) and Rohrbough and associates (Rohrbough et al. 2002) currently recommend selective minimal resection of posteromedial osteophytes in addition to UCL reconstruction (Purcell et al. 2007).

34.10 Reviews

Using modified Jobe techniques, Cain et al. in 2010 reported 83% excellent results (610 of 733 reconstructions) in the largest series reported (Cain et al. 2010).

There are two systematic reviews of UCL reconstruction in throwing athletes. Purcell et al. (2007) reviewed four retrospective cohort studies that reported outcomes.

Return to play ranged from 68 to 92%, with the number of professional athletes ranging from 31 to 65%. The average time to return to throwing was 4 months and

return to play was 12 months. The outlook was less optimistic for patients who had prior surgery (diagnostic arthroscopy, loose body removal, repair of UCL, or osteophyte resection).

Vitale and Ahmad (2008) performed a systematic review to assess various surgical techniques. They identified eight retrospective cohorts of throwing athletes that achieved 83% excellent results after UCL reconstruction. The transition to muscle-splitting approach from flexor-pronator mass detachment was associated with improvement, from 70% excellent outcomes and 20% ulnar nerve neuropathy to 87% excellent outcomes and 6% ulnar nerve neuropathy.

The docking technique was also associated with better outcomes, with 90% excellent results and 3% rate of postoperative ulnar nerve neuropathy. The modified docking technique using a three-strand graft with double anterior bundle carried 95% excellent results and a 5% incidence of postoperative ulnar nerve neuropathy.

This compared with the figure-of-eight technique in which there was a collective 76% excellent result and 8% rate of ulnar nerve neuropathy. Vitale and Ahmad (2008) noted that 48% of patients received ipsilateral palmaris graft and 34% received contralateral palmaris graft. Gracilis tendon graft was used in 10%. Cain et al. (2010) found no statistical difference between graft choice and return to play.

34.11 Rehabilitation

The elbow is immobilized in a splint for 10 days to allow the skin and soft tissues to heal. Sutures are removed at that time, if necessary, and active wrist, elbow, and shoulder range-of-motion exercises are initiated. After 4–6 weeks, strengthening exercises are begun while avoiding valgus stress until 4 months after surgery. At 4 months, the patient begins a throwing program consisting initially of ball tosses of 30–40 feet for about 15 min 2–3 times a week. At 5 months, the patient may increase the tossing distance to 60 feet, and at 6 months, the patient may throw lightly from the windup. At 7 months, a graduated program of range-of-motion, strengthening, and total body conditioning exercises is undertaken. Throwers and pitchers are limited to throwing at half speed, gradually increasing the duration of the session to 25–30 min. Pitchers are permitted to throw from the pitching mound and progress to 70% of maximum velocity during the eighth or ninth month. Over the next 2–3 months, the duration of throwing sessions and velocity are increased incrementally to simulate a game situation. Throwing in competition is permitted at 1 year if the shoulder, elbow, and forearm are pain-free while throwing and full strength and range of motion have returned. Throughout the rehabilitation phase, careful supervision and focus on body and throwing mechanics should be emphasized. Up to 18 months may be required to regain preoperative ability and competitive level with accurate ball control. Relatively shorter periods are required for other player positions or overhead sports.

34.12 Ulnar Neuritis

The superficial location of ulnar nerve makes it particularly susceptible to several mechanical factors, including compression, traction, and irritation in throwing athletes (Boatright and D'Alessandro 1996).

During the acceleration phase of the throwing motion, the ulnar nerve is subject to longitudinal traction (Schickendantz 2002).

Potential site of compression proximal to the cubital tunnel includes a thick band of fibrous tissue located 8–9 cm proximal to the medial epicondyle. This has historically been referred to as the "Arcade of Struthers," which in reality is neither an arcade nor did Sir John Struthers define it (Bartels 2004; von Schroeder and Scheker 2003).

Instead, the medial intermuscular septum and the internal brachial ligament converge to form this thick band of tissue at the point where the ulnar nerve transitions from the arm.

Distal sites of potential compression include the area between the FCU (flexor carpi ulnaris) and the medial forearm musculature. Recently, Li et al. (2012) even reported compression through the anconeus epitrochlearis, which may be hypertrophied in overhead throwing athletes. The anconeus epitrochlearis is an anomalous muscle originating from the medial border of the olecranon and inserting onto the medial epicondyle. It is present in up to 34% of arms, making it the most common anomalous muscle in the upper extremity (Masear et al. 1988). This muscle overlies the ulnar nerve posteriorly and may cause compression of the nerve with elbow flexion. Aoki et al. (2005) found a hypertrophic medial head of the triceps impinging on the ulnar nerve as the elbow was flexed greater than 90° in a series of adolescent baseball players with ulnar neuropathy.

The Osborne ligament is the roof of cubital tunnel. It is bordered laterally by the elbow, anteriorly by the medial epicondyle, and medially by the origin of the FCU (Bradshaw and Shefner 1999; Huang et al. 2004) and represents the predominant compression site in the cubital tunnel. As the elbow flexes, the Osborne ligament becomes taut, trapping the ulnar nerve between itself and the medial collateral ligament. The pressure inside the cubital tunnel increases sevenfold to 20-fold, causing not only deformation of the nerve but also compromising its vascular supply (Posner 1998).

Osteophyte formation within the medial aspect of the elbow also may lead to narrowing of the cubital tunnel, as well as loose bodies, or synovitis.

As the ulnar nerve enters the forearm, it is subject to compression at the aponeuroses of both the flexor carpi ulnaris and the flexor-pronator mass.

More than 40% of athletes with valgus instability experience ulnar neuritis secondary to irritation from the inflammation of the UCL as well as increased stretch from valgus stress. Approximately 60% of athletes with medial epicondylitis develop ulnar nerve symptoms (Conway et al. 1992; Boatright and D'Alessandro 1996; Gabel and Morrey 1995a, b).

Repetitive tensile force on the ulnar nerve has been implicated as a cause of ulnar neuritis (Rokito et al. 1996; Glousman 1990).

The throwing motion subjects the elbow to significant valgus stress, which in turn causes traction on the medial structures of the elbow, including the ulnar nerve. The early acceleration phase causes an average ulnar nerve strain of 5–13% (Aoki et al. 2005; Toby et al. 1998).

Additionally, the nerve has been noted to undergo axial translation of 12 mm as the elbow ranges from full flexion to full extension (Aoki et al. 2005).

Continuation of the throwing motion with further elbow flexion and shoulder abduction causes the intraneural pressure to rise six times the resting level. This increased pressure is attributed to nerve stretch, tightening of the cubital tunnel, and compression (Chen et al. 2001). Repetitive motions can induce chronic changes to the ulnar nerve and surrounding soft tissues, potentially leading to nerve fibrosis and ischemia.

34.13 History and Examination

A thorough history may reveal pain and paresthesias in the ring and small fingers and intrinsic weakness in the hand. Throwing athletes may complain of loss of ball control or coordination.

The repetitive flexion and extension motions caused by the throwing cycle may exacerbate an ulnar nerve already prone to subluxation.

The elbow flexion test with the elbow maintained in maximum flexion and wrist in extension for 1 min should be conducted.

The carrying angle of the elbow found to be of abnormal valgus angulation also may predispose to traction injury of the ulnar nerve.

The throwing athlete with ulnar nerve subluxation may describe a popping or snapping sensation at the medial elbow. This may be accompanied by pain or paresthesias both at the elbow and within the ulnar nerve distribution distally.

Physical examination may demonstrate weakness of the intrinsic musculature of the hand, the flexor digitorum profundus to the ring or small finger, or the first dorsal interosseous. Note any positive Tinel sign over a potential point of compression of the nerve. However, a Tinel sign should be interpreted within the context of the patient's complaints; 10% of the healthy population may have a positive Tinel sign at the cubital tunnel (Rayan et al. 1992).

However, the negative predictive value of a Tinel at the elbow is 98% (Cheng et al. 2008). The ulnar nerve should be palpated along its course to assess for enlargements and for subluxation during flexion.

Electrodiagnostic testing may be useful in diagnosing ulnar neuropathy; however, changes may not be seen until disease has advanced. Testing should be performed with the elbow in flexion, as the length of the ulnar nerve is often underestimated with the elbow extended (Posner 1998). A negative electrodiagnostic test does not rule out ulnar neuritis (Del Pizzo et al. 1977; Rokito et al. 1996).

34.14 Treatment

Treatment for ulnar neuritis generally begins with a period of activity modification, anti-inflammatory medications, and physical therapy. Corticosteroid injections may cause further damage to already injured ligamentous and cartilaginous structures and should be avoided. Nocturnal extension splinting in semi-extension or elbow pads can be considered. Generally 6 weeks of abstinence from throwing is recommended. Once symptoms begin to resolve, an interval throwing program is implemented. Ulnar neuropathy in overhead throwing athletes typically stems, however, from an underlying cause, and as throwing is resumed, symptoms likely resurface. Indeed, the role of nonoperative treatment in high-level throwing athletes is limited and consideration may be given to early operative intervention.

Indications for operative management include failed nonoperative treatment, persistent ulnar nerve subluxation, symptomatic tension neurapraxia, and concomitant medial elbow problems that require surgery (Chen et al. 2001).

The surgical options for treatment include decompression (in situ) of the ulnar nerve, medial epicondylectomy, and anterior transposition of the nerve. Simple decompression and medial epicondylectomy are prone to failure in overhead throwing athletes. Decompression may address some of the compressive forces within and around the cubital tunnel but does not address irritation from traction and repetitive motion. Furthermore, in cases of ulnar nerve subluxation, decompression fails to stabilize the nerve.

Medial epicondylectomy aims to prevent traction irritation to the nerve as it passes posterior to the medial epicondyle. Well-recognized complications include, however, nerve instability, valgus instability from iatrogenic injury to the UCL, and weakness from disruption of the flexor-pronator mass.

Anterior transposition of the ulnar nerve is the mainstay of surgical management of ulnar neuritis and can be performed either subcutaneously or submuscularly (Charles et al. 2009; Chung 2008; Macadam et al. 2008).

Whichever method is chosen, critical importance must be placed on protecting the medial antebrachial cutaneous nerve, avoiding creation of new compression proximally or distally and early range of motion to prevent scar formation (Mackinnon 2009).

Subcutaneous transposition has the advantage of less surgical morbidity to the flexor-pronator mass and may be recommended in patients undergoing concomitant UCL reconstruction (Cain et al. 2003; Rettig and Ebben 1993; Azar et al. 2000). The main disadvantage of the subcutaneous technique is its susceptibility to direct trauma (Boatright and D'Alessandro 1996; Rokito et al. 1996; Glousman 1990).

Other concerns include potential for developing instability and recurrence of symptoms from new compression under the subcutaneous fasciodermal sling. Subcutaneous transposition is performed via a 6-cm to 8-cm incision that parallels the ulnar nerve posterior to the medial epicondyle. Once the ulnar nerve is identified, it is mobilized while preserving the accompanying vascular structures. All sites of compression of the nerve must be released, particularly proximally and distally. A finger is passed proximally to ensure the internal brachial ligament does not contribute to nerve compression of the nerve and should be released. The same technique distally evaluates the fascia of the flexor carpi ulnaris. The first motor branch of the ulnar nerve to the flexor carpi ulnaris may need to be mobilized to allow for untethered anterior transposition.

A segment of the intermuscular septum is resected, and a judicious pocket is created in the subcutaneous tissue into which the nerve is placed. The nerve is checked once more to ensure smooth gliding with flexion and extension of the elbow. The patient may be placed in a sling until the first postoperative visit when early range-of-motion exercises are begun.

Submuscular transposition begins with a slightly larger incision than its subcutaneous counterpart. After the nerve is mobilized as described previously, a z-plasty incision is made in the tendon of the flexor-pronator origin. The musculofascial flaps are elevated, taking care not to disrupt the first motor branch to the flexor carpi ulnaris. The nerve is laid deep to the flexor-pronator mass next to the median nerve. The nerve is inspected throughout its course to ensure that no proximal or distal site of compression exists with elbow range of motion. The flexor-pronator origin is repaired in a slightly lengthened position with nonabsorbable suture. The wound is irrigated and closed and a posterior splint is applied with the elbow at 90° of flexion for 2 weeks. Passive range-of-motion exercises and formal therapy are begun at the first postoperative visit.

Submuscular transposition involves greater surgical dissection in the medial soft tissues and a lengthier postoperative rehabilitation course but provides thorough decompression of the nerve while protecting it from direct and indirect trauma. The outcomes of ulnar nerve transposition in overhead athletes support both approaches in throwing athletes. Rettig and Ebben (1993) performed 21 anterior subcutaneous transposition procedures in 20 athletes for failed conservative management of cubital tunnel syndrome. All athletes returned to play at an average of 12.6 weeks. The investigators recommended subcutaneous transposition in light of faster postoperative recovery and rehabilitation.

34.15 Medial Epicondyle Apophysitis

In skeletally immature throwers, both the static (UCL) and dynamic (flexor-pronator muscle group) medial stabilizers attach to the medial epicondyle, thus conferring all of the static and dynamic stress to the medial epicondylar physis. Valgus and contractile forces across the elbow that result in ligament and tendon injury in the adult thrower lead to injury to the weaker medial epicondyle apophyseal plate in the skeletally immature thrower.

Bennett coined the term Little Leaguer's elbow to describe the clinical and radiographic changes associated with these medial-sided traction injuries in skeletally immature athletes (Bennett 1959).

Symptomatic injury is associated with the combination of repetitive forces on the medial elbow and inadequate intervals of rest (Benjamin and Briner 2005; Lyman et al. 2002, 2001).

Repetitive valgus loading can lead to apophyseal fragmentation or avulsion of the medial epicondyle apophysis as well as changes in the radiocapitellar joint laterally.

Medial epicondylar apophysitis should be suspected in adolescent throwing athletes presenting an insidious onset of medial elbow pain accompanied by a steady decrease in velocity and accuracy.

These young athletes complain a point tenderness over the medial epicondyle and pain with valgus stress of the elbow. More advanced cases may exhibit decreased range of motion of the elbow.

AP, lateral, and axial radiographs of both elbows for comparison should be obtained. In the case of normal films, a stress view may be necessary to determine physeal versus ligamentous injury. Widening of the epiphyseal lines or hypertrophy of the medial epicondyle suggests chronic and advanced injury. Medial epicondylar apophysitis is treated by complete cessation of throwing injuries. Ice, massage, and oral analgesia may be used as adjuncts. Splinting may be required for refractory cases or patients with pain at rest. Pediatric athletes with stable avulsion fractures of the medial

epicondyle and minimal displacement can be treated in a long-arm cast for 3–4 weeks with excellent results (Lawrence et al. 2013).

Prevention of medial epicondylar injury in pitchers through limiting pitch counts and innings pitched should be performed (Olsen et al. 2006; Lyman et al. 2002).

Contrary to popular thought, pitch count is more important than type of pitch thrown (Dun et al. 2008).

Patients with avulsion fractures typically have significant swelling and decreased ROM. Radiographs may show a subtle widening of the physeal plate and comparison views of the uninvolved limb are vital. MRI typically shows more findings than radiographs; however, these do not necessarily have clinical correlation and do not change management (Wei et al. 2010).

Although activity modification is successful in apophysitis, treatments of epicondylar avulsions remain controversial (Torg 1972).

Nonoperative management is successful in the management of minimally displaced fractures without instability. These injuries can be treated with splint immobilization for 5–7 days, followed by early motion (Woods and Tullos 1977; Hines et al. 1987; Ireland and Andrews 1988).

Lawrence and colleagues (Lawrence et al. 2013) recommend nonoperative management in young athletes with low energy medial epicondyle avulsions, a stable elbow, and minimal fracture displacement (5.3 ± 2.0 mm). Open reduction and internal fixation can be successful in athletes who sustain more significant trauma, who have elbow laxity or instability, or who have significant fracture fragment displacement (7.1 ± 2.9 mm) after a fracture of the medial epicondyle.

34.16 Flexor-Pronator Mass Tendonitis

It is a relatively frequent finding in overhead throwing athletes, as well as in racquet sports participants (Andrews et al. 1996; Leach and Miller 1987; Plancher et al. 1996; Stapleton and Baker 1996; Vangsness and Jobe 1991).

The involved muscles include the flexor carpi radialis, pronator teres, palmaris longus, and infrequently the flexor carpi ulnaris and the flexor digitorum superficialis. Chronic medial epicondylitis can be difficult and frustrating to treat (Dehaven and Evarts 1973).

The act of throwing during late cocking and early acceleration phases places a valgus tensile stress across the elbow, specifically on the flexor-pronator mass. Pronation of the forearm with the elbow in extension further stresses the flexor-pronator origin (Leach and Miller 1987). The flexor-pronator muscles act as dynamic stabilizers of the elbow against valgus stress and help to prevent injury to the medial ligamentous complex (Hamilton et al. 1996; Glousman et al. 1992; Digiovine et al. 1992; Sisto et al. 1987; Grana 2001).

Sufficient repetitive stress leads to muscle fatigue, weakness, and microtears within the flexor carpi radialis or pronator teres muscles near their origins on the medial epicondyle (Dehaven and Evarts 1973; Plancher et al. 1996). This repetitive microtrauma is followed by fibroblastic tendinosis with proliferation of vascular granulation tissue (Nirschl 1992).

The process becomes chronic with a failed healing response (Ciccotti 1999).

The histology of the tendon becomes abnormal and can ultimately lead to frank avulsion of the flexor-pronator origin (Norwood et al. 1981).

34.17 History and Examination

The typical presentation includes an athlete with medial elbow pain during the late cooking or acceleration phase of throwing with continuation during ball release as the forearm is pronated and the wrist flexed. Athletes will complain of pain over the origin of the flexor-pronator mass. The location of tenderness elicited by palpation on examination should be carefully recorded. Grip strength is decreased in patients with medial epicondylitis compared with control subjects, although the magnitude of impairment is less than that seen in patients with lateral epicondylitis (Pienimaki et al. 2002). The examiner should assess the competency of the UCL with a valgus stress test. Indeed, the main differential diagnosis in these cases should include injury to the UCL. In flexor-pronator injuries, athletes have tenderness to palpation just distal to the medial epicondyle along the common origin. Meanwhile, in UCL injuries, the tenderness is typically posterior and distal to that of flexor-pronator pain along the sublime tubercle. Lastly, pain with flexor-pronator injury should be exacerbated with wrist flexion and elbow extension.

Combined UCL and flexor-pronator injuries are not uncommon. Because associated ulnar neuropathy is frequent in patients with medial epicondylitis (Vangsness and Jobe 1991; Gabel and Morrey 1995a, b), a careful neurologic examination should be performed to look for evidence of ulnar neuritis, including Tinel sign (radiating pain with percussion at the cubital tunnel), cubital tunnel compression testing, 2-point discrimination testing of the fifth digit, and assessment of hypothenar atrophy in advanced cases.

Imaging studies, such as plain radiographs, may show calcifications or traction osteophytes at the flexor-pronator origin. Kijowski and De Smet (2005) assessed MRI findings from 13 patients with clinically diagnosed medial epicondylitis and reported thickening and increased signal intensity within the common flexor tendon and surrounding soft tissue edema seen in both T1- and T2-weighted images compared with age-matched controls. Clinical evaluation remains adequate for diagnosis in most cases. MRI may be more use-

ful when used to rule out other pathologies, such as osteochondritis dissecans lesions, medial collateral ligament insufficiency, or loose bodies (Taylor and Hannafin 2012).

34.18 Treatment

The management of medial epicondylitis in overhead throwing athletes focuses on nonoperative treatment.

The athlete should cease throwing activities but can continue with active range-of-motion exercises accompanied by ice and anti-inflammatory agents. Once the patient's pain has resolved, an interval throwing program is instituted with anticipated return to preinjury level of play. Athletes who fail initial conservative therapy may benefit from a well-placed corticosteroid injection. However, corticosteroid injections improved symptoms at 6 weeks but showed no difference when compared with controls at 3–12 months (Stahl and Kaufman 1997).

When a patient is injected for medial epicondylitis, particular caution must be taken to protect the ulnar nerve because of its proximity.

No data are currently available on the efficacy of PRP injections for flexor-pronator injury in overhead throwing athletes.

Recalcitrant cases should prompt the clinician to investigate other causes of medial elbow pain, particularly UCL injury. In the absence of concomitant injury, the athlete may benefit from open debridement and repair of the flexor-pronator mass to the medial epicondyle if conservative treatment fails 6–12 months (Dlabach and Baker 2001).

The patient is placed supine on the operating table and general anesthesia is obtained. An arm tourniquet is applied proximally. The involved extremity is then prepared and draped in standard fashion. The arm is exsanguinated and the tourniquet inflated. A 7-cm curved incision is made just posterior to the medial epicondyle. The cutaneous nerves and the ulnar nerve are identified and protected during the procedure.

The proximal flexor-pronator mass is exposed longitudinally from its origin and the pathologic tissue is identified. The pathologic tissue is excised, leaving the normal tissue of the attachment to the medial epicondyle intact. The ulnar collateral ligament is examined for injury if one is suspected. The defect in the flexor-pronator origin is repaired with absorbable suture.

The ulnar nerve is transposed in patients who have ulnar nerve symptoms or pathoanatomy that is found at the time of surgery. The tourniquet is deflated and hemostasis is obtained. Subcutaneous tissue is closed with absorbable suture, and skin closure is performed with a running subcuticular Prolene suture. To avoid confusion during the postoperative assessment of ulnar nerve function, we do not inject the wound with a local anesthetic. A dressing and a posterior splint are applied with the elbow in 90° of flexion.

Postoperatively, patients begin wrist and hand motion exercises immediately. The sutures and splint are removed 1 week after surgery and elbow range-of-motion exercises are begun. Strengthening exercises are started when full range of motion is achieved, typically 3 weeks after surgery. If the patient has achieved normal strength, a gradual return to sports is allowed at 3 months. A longer period of immobilization and slower progression of rehabilitation are indicated in patients who undergo ulnar nerve transposition or ulnar collateral ligament reconstruction.

Cases in which ulnar neuritis accompanies medial epicondylitis have a less favorable outcome when treated surgically than those with isolated medial epicondylitis (Kurvers and Verhaar 1995).

Patients with refractory symptoms treated surgically will likely see improvement in pain but may not return to their sporting activities. Ollivierre et al. (1995) reported on 50 cases of surgical treatment for medial epicondylitis. At an average of 37 months of follow-up, objective strength testing showed improvement with relief of preoperative pain. Of note, however, 20% of patients did not return to their previous recreational sporting activities.

Because surgical treatment is rarely required, failure of nonoperative treatment should heighten awareness of other underlying pathology. Overhead throwers are also vulnerable to pronator syndrome, which is compression of the median nerve caused by hypertrophy of pronator teres secondary to repetitive activity. Athletes complain of vague, fatigue-like pain over the proximal volar aspect of forearm exacerbated by resisted forearm pronation and wrist flexion.

If nonoperative management with activity modification and anti-inflammatory medications fails, then surgical exploration with division of superficial head of the pronator teres and decompression of the median nerve may be required.

Conclusions

Medial elbow overuse injuries are likely to occur with greater frequency as more adolescents become active in competitive sports, as the age at which they begin to specialize in one sport decreases, as the seasons become longer with multiple games and teams, and as the competitive level increases. The characteristics of these overuse injuries change as the bony elbow structure of the player reaches skeletal maturity, shifting from apophyseal injuries to midsubstance UCL injuries. Regardless of the specific tissue that is injured, all result from the high elbow joint loading volume (combined frequency, intensity) associated with throwing. Several overuse risk factors have been identified including heavy training loads, early sport-specific training, year-round throwing, participation in multiple sports, training errors, musculotendon strength and extensibility

deficiencies, faulty equipment, and unqualified coaching or other supervisory practices (Gregory and Nyland 2013; Caine et al. 2008; Demorest and Landry 2003). Nevertheless, modification to throwing biomechanics may not necessarily lead to improved clinical outcomes because the stresses from repetitive throwing may be the driving force to injury (Patel et al. 2014).

Overall, in any overhead throwing athlete, UCL attenuation or failure must be ruled out but should not be the only pathology considered (Patel et al. 2014).

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Osteochondritis Dissecans in "Little League" Players and Gymnast

35

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35.1 Introduction

Osteochondritis dissecans (OCD) of the capitellum (Fig. 35.1) is a disabling disease that affects skeletally immature athletes subjected to repetitive compression of the radiocapitellar joint. Its exact etiology, natural history, and therapeutic management are not yet well known (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010).

The aim of this chapter is to provide a brief review of some of the latest insights into the diagnostic tools and treatment options for this disease.

35.1.1 Definition

OCD was firstly described by Konig in 1887 (Nagura 1960). Konig suggested that an inflammatory process of the cartilage and subchondral bone caused necrosis of these tissues, thereby leading to the formation of osteochondral fragments and loose bodies. Since then, several histological studies (Nagura 1960; Schenck and Goodnight 1996; Pappas 1981) have demonstrated the absence of inflammatory cells. However, the term "osteochondritis dissecans" is still widely used today to describe the condition.

The latest definition of OCD was given by Research in Osteochondritis of the knee study group (Edmonds and Polousky 2013) which emphasizes the following characteristics of the disease: it is a focal idiopathic impairment of the subchondral bone, a condition that, by compromising adjacent articular cartilage, may potentially lead to an early onset of osteoarthritis. Takahara et al. (1999) has suggested that degenerative changes in the radiocapitellar joint can be seen in 50% of OCD patients.

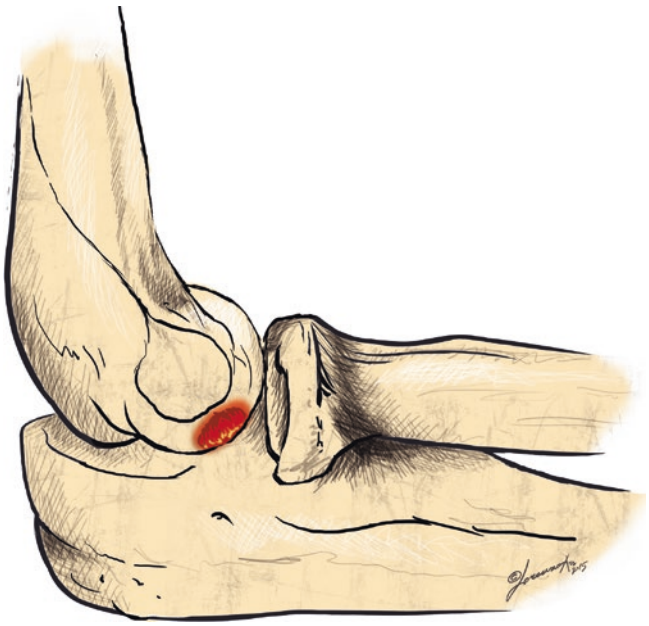


Fig. 35.1 Typical localization of capitellar osteochondritis dissecans

OCD, which may affect different bone junctures of the lower and upper limbs, has the highest prevalence in the knee. In the upper limbs the elbow is the most commonly affected site. In the latter case, OCD usually affects the humeral capitellum, although the trochlea, the radial head, and the olecranon may also be involved (Baker et al. 2010).

In recent years, there has been an increasing incidence of OCD lesions in the capitellum. A possible explanation for this phenomenon is the progression in accuracy of diagnostic tools, such as MRI, and a major involvement of young athletes in highly competitive sports (Nissen 2014). OCD frequently affects young athletes involved in sports requiring repetitive stress in compression of the elbow, such as gym-

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nastics or baseball (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010). Kida et al. (2014), for example, evaluated 2433 baseball players aged between 12 and 18 years; ultrasound screening followed by radiographic examination showed a prevalence of OCD in 3.4% of these players.

35.2 Differential Diagnosis

Many diseases of the elbow come into differential diagnosis with OCD, and some of them are wrongly mistaken as its synonyms.

Panner's disease is another disorder of the immature capitellum and it must be differentiated from OCD (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Yadao et al. 2004; Kobayashi et al. 2004; Bradley and Petrie 2001). It is an osteochondrosis of the entire capitellum, similar to Legg-Calvé-Perthes of the hip that usually occurs in children under the age of 10 (range 7–12 years) (Yadao et al. 2004; Kobayashi et al. 2004; Bradley and Petrie 2001), without association to repetitive trauma. It represents a self-limiting disease with reossification and complete resolution of symptoms without sequelae (Schenck and Goodnight 1996; Pappas 1981; Yadao et al. 2004; Bradley and Petrie 2001). The radiographic images show a progressive flattening and sclerotic areas of the entire capitellum (Bradley and Petrie 2001).

The term *Little League elbow* includes a number of diseases that affect the elbow of teenage baseball players: apophysitis of the medial epicondyle, delayed or accelerated growth of the medial epicondyle, osteochondrosis and osteochondritis dissecans of the capitellum, osteochondritis of the radial head, ulnar hypertrophy, and olecranon apophysitis (Bradley and Petrie 2001).

35.3 Etiopathogenesis

The etiology of OCD is still uncertain and it may be multifactorial. Evidences for a possible genetic predisposition are supported by patients with bilateral OCD (Bednarz et al. 1998) or by its manifestation in twins (Kenniston et al. 2008). Nonetheless, no conclusive evidence is yet available on this point. In the elbow repeated microtraumas (e.g., in young baseball players (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Schenck and Goodnight 1996; Takahara et al. 1999; Kida et al. 2014; Yadao et al. 2004; Bradley and Petrie 2001; Singer and Roy 1984) or gymnasts (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Jackson et al. 1989)) and ischemia play key roles in OCD development. Under physiological conditions, the forces transmitted through the elbow are unequally shared between the ulno-humeral (40%) and the radiohumeral joint (60%) (Singer and Roy 1984; Jackson et al. 1989). Schenck et al. (1994) in a cadaver study showed a mechanical mismatch between the radial head and the capitellum. The central part of the radial head is indeed significantly stiffer than the capitellum. In the pitchers extensive throwing over long periods of time can overstress the medial elbow complex, specifically the medial collateral ligament and the origin of the flexor-pronator (Ruchelsman et al. 2010; Bradley and Petrie 2001; Singer and Roy 1984; Jobe and Nuber 1986). This leads both to an increase in valgus stress during the early and late cocking phase of throwing and to an increase in the compression and shear forces at the radiohumeral articulation (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Singer and Roy 1984).

Likewise, in gymnasts the repeated gestures of weight-bearing of the upper limbs with the elbow joint in extension lead to the transmission of cutting and compression forces that are much greater in the lateral compartment (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Jackson et al. 1989). Thus, repeated microtraumas to an immature epiphysis with a precarious vascularization can over time generate subchondral bone lesions which may progress toward necrosis and stress fractures of the capitellum (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Schenck and Goodnight 1996; Kobayashi et al. 2004; Bradley and Petrie 2001; Singer and Roy 1984).

Another key factor is represented by ischemia. Haraldsson (1959) described the vascular anatomy of the distal humerus, showing that between the ages of 5 and 19 years, only one or two terminal vessels enter from back and across in the capitellum, with the absence of collateral metaphyseal circle. Repetitive trauma can damage these small blood vessels, hindering the reparative processes involving the subchondral bone.

In particular, whereas articular cartilage initially remains intact, hyperemia and edema of the subchondral bone are the first pathological changes in elbow OCD (Yadao et al. 2004). Subsequently, the interface area between the subchondral necrotic region and the healthy bone is filled by vascularized granulation tissue that progressively replaces the necrotic bone.

Generally, if the articular cartilage remains intact and trauma ends, the necrotic bone is completely reabsorbed and replaced with the normal bone. However, if the injuries persist, the loss of the subchondral support can lead to the breakdown of articular cartilage and to necrotic debris which may detach, forming loose bodies in the joint (Yadao et al. 2004).

Kusumi et al. (2006) have suggested that early pathological changes are caused by damage to the articular cartilage induced by repetitive stress. In the later stages of the condition, stress fractures of the subchondral bone with minimal necrosis, along with degenerative and reparative processes involving these structures, take place. Finally, the separation from the cartilage occurs and develops in the underlying subchondral bone.

35.4 Clinical Presentation

OCD usually occurs in young athletes like baseball pitchers, gymnasts, volleyball, and water polo players aged between 11 and 17 years, with a widespread, nonspecific, and often mild pain after exercise (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Schenck and Goodnight 1996; Pappas 1981; Yadao et al. 2004; Bradley and Petrie 2001). The pain is progressive and sometimes localized to the lateral side of the elbow (Bradley and Petrie 2001). The dominant limb is almost always involved, while the bilateral involvement has been reported between 5% and 20% (Shaughnessy 2000). Rarely the patient associates the onset of pain to a specific traumatic event. The rest, anti-inflammatory therapies and the changes of the sport activity, leads to an improvement of symptoms. Usually, athletes try to work on the pain, treating it only symptomatically, and they have several episodes of pain over the years until they experience a feeling of joint block and sharp pain. Typically several months or years pass from symptoms onset to the diagnosis. Symptoms that are most commonly associated with pain are swelling and loss of the last degrees of extension; loss of flexion is less common, while pronation and supination movements are rarely affected. Once loose bodies are formed, athletes begin to experience joint blocks with feelings of catching, clicking, and grinding.

Upon physical examination, it is necessary to evaluate (1) the articular range of motion, both in flexion-extension and in pronation-supination, (2) the presence of a swelling, (3) the stability of the ligaments, in particular the ulnar collateral ligament, and the presence of any posterolateral instability. Palpable tenderness of the elbow at the level of the radiocapitellar joint is also checked. Among the different provocative maneuvers, the active radiocapitellar compression test (Yadao et al. 2004; Bradley and Petrie 2001) is highly recommended: actively the patient prone and supine forearm in full extension, compression of the radiocapitellar joint through dynamics muscle contraction can reproduce the symptoms. During the elbow pronation and supination is frequent to appreciate articular cracklings. It must be kept into consideration that often athletes are clinically evaluated during the rest periods, in which the symptoms improve and in which the examination may be negative.

35.5 Imaging Evaluation

Standard anteroposterior (AP) and lateral radiographs of the elbow represent the initial diagnostic tests to visualize suspected OCD. An additional oblique projection or AP with the elbow flexed to 45° (Takahara et al. 1998), or an axillary projection (Nissen 2014) of the elbow can also be useful. Most important, medical examiners should recognize the chronological sequence of appearance of ossification centers (Bradley and Petrie 2001; Bradley 1994): the capitulum humeri at 1 or 2 years, the radial epiphysis at 3 or 4 years, the medial epicondyle at 5 or 6 years, the trochlea at 9–10 years, the lateral epicondyle at more than 10 years, and the common epiphysis. Alterations in the ossification centers can be seen only when compared with the opposite side. In the early stages of OCD, X-ray images can be negative (Ruchelsman et al. 2010; Bradley and Petrie 2001; Takahara et al. 1998). Classically, in this phase, images may show areas of radiolucency and scarcity of capitellum with flattening or irregularities of the joint surface. An edge of sclerotic bone often surrounds the radiolucent crater, which is typically located either in the center or in the anterolateral area of the capitellum (Ruchelsman et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Takahara et al. 1998). In the late stages of the disease, images may reveal loose bodies, a widening of the radial head and osteophytes formation.

Nowadays an essential diagnostic tool for diagnosis and study of OCD is the magnetic resonance imaging (MRI) (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001). MRI allows an accurate study of the articular cartilage and the underlying subchondral bone; it gives information about the presence of bone edema, joint effusion, reactive synovitis, the continuity of the articular cartilage, and the separation of osteochondral fragments. It allows to detect the disease in the early stages, when X-rays are normal or show only confounding changes (Bowen et al. 2001). Initial alterations are represented by lesions with a hypointense signal on T1 with no change in T2 (Ruchelsman et al. 2010; Baker et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Takahara et al. 1998). In the later stages intensity alterations are present in T1 and T2 (hyperintensity and cyst formation around the lesion) (Ruchelsman et al. 2010; Baker et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Takahara et al. 1998). An advantage of MRI is that it can accurately measure the magnitude, scope, and stability of the lesion. Kijowski and De Smet (2005) have noted that in unstable lesions of the capitellum, as well as of the knee, a peripheral ring of hyperintense signal or an underlying fluid-filled cyst is detectable on T2 images. Additional information on the stability and vitality of the lesions can be obtained with intravenous MRI contrast agents (gadopentetate-dimeglumine). Widespread enhancement of contrast in the fragments suggests a good tissue viability. Diffuse enhancement at the fragment subchondral bone interface indicates the presence of granulation tissue and therefore instability of the osteochondral pad (Bowen et al. 2001; Kijowski and De Smet 2005; Peiss et al. 1995).

A potential source of mistake in resonance images evaluation is the presence of a pseudo-defect of the capitellum which can occasionally be confused with an OCD (Ruchelsman et al. 2010; Bradley and Petrie 2001). This

lesion occurs in the posteroinferior junction, between the articular and the nonarticular surface, whereas a true OCD lesion is located anteriorly.

The computed tomography (CT scan) and ultrasound are accessory exams that can be useful sometimes. CT scan is important to obtain an accurate assessment of the subchondral bone, the size, and the depth of the lesion and to better define the location of loose bodies. The ultrasonographic examination can be useful in screening athletes at particular risk, especially if asymptomatic: it may show an irregularity, a breaking of the continuity of normal echogenic line of the profile of the capitellum (Kida et al. 2014).

35.6 Classification of OCD Lesions

Traditionally OCD lesions of the capitellum were classified into three types, according to their aspects on X-ray, stable, unstable but attached, and unstable but detached (Bradley and Petrie 2001; Shaughnessy 2000), which correspond to the three degrees of Minami's radiographic classification, developed in 1979.

Minami (Minami et al. 1979):

- Grade 1: cystic translucent shade in the middle or side of the capitellum
- Grade 2: clear dividing line between the lesion and the adjacent subchondral bone
- Grade 3: presence of loose bodies

Later, *Iwase* (Iwase and Igata 1988) divided the grade 2 into two other subgroups:

- Grade 2A: split lesion or small fragment without sclerosis
- Grade 2B: fragment demarcated by sclerosis

More recently, Takahara et al. (2007) reviewed this classification based on X-ray findings on the basis of his experience studying the outcome of 106 patients treated for OCD, dividing lesions in two main groups with different prognostic and therapeutic values: stable and unstable lesions.

- Grade 1: STABLE LESIONS: localized flattening or radiolucency
- Grade 2: UNSTABLE LESIONS: fragments not moved
- Grade 3: UNSTABLE LESIONS: fragments detached and moved

A stable lesion refers to lesion that heals completely with conservative therapy and that occurs in an immature capitellum with an open growth plate, classified as grade I, with normal or near normal range of motion. An unstable lesion, which usually requires a surgical treatment, refers to those that occur in a mature capitellum with a closed growth plate, radiographic grade II or III, and a reduced range of motion greater than or equal to 20°.

OCD lesions have been classified also on MRI bases. Classically the classification system developed by Nelson et al. (1990), used for OCD of the knee and talus, is also commonly used for the capitellum:

- Grade 0: normal
- Grade 1: intact cartilage with signal changes
- Grade 2: hyperintense signal of articular cartilage
- Grade 3: thin hyperintense ring around the osteochondral fragment indicating the presence of synovial fluid
- Grade 4: loose body with mixed or hypointense signal free in articulation or even in the lesion site

Bradley and Petrie (2001) in 2001 refined Minami's classification on the basis of their MRI findings and divided OCD lesions into the following four groups specifically for the capitellum:

- Group 1A (very early lesion): normal X-rays and MRI images withT1 hypointensity and T2 normal intensity.
- Group 1B: radiographic images of thinning, flattening, or sclerosis of the capitellum, on MRI T2 hyperintensity.
- Groups 2 and 3 are the same as described in Minami's classification.
- Group 4: "bipolar" lesions (alterations also in the radial head surface).

Kosaka et al. (2013), as the previous authors, combined MRI findings with the radiographic classification, distinguishing four stages:

- Translucent stage: corresponding to radiographic grade 1.
- Early detached stage: corresponding to radiographic grade 2 in absence of hyperintense signal on T2 around the lesion.
- Late detached stage: corresponding to radiographic grade 2 with hyperintense signal on T2.
- Displaced stage: corresponding to radiographic grade 3. Furthermore Kosaka et al. (2013) classified OCD lesions on the basis of their localization, which is an important factor in surgical management especially in the preoperative planning (Fig. 35.2).
- Centralized type.
- Lateral localized type (<33% of the width of the capitellar articular surface).
- Lateral widespread type (>33%).

Baumgarten et al. (1998) proposed an arthroscopic classification of capitellum OCD in 5°. This classification was

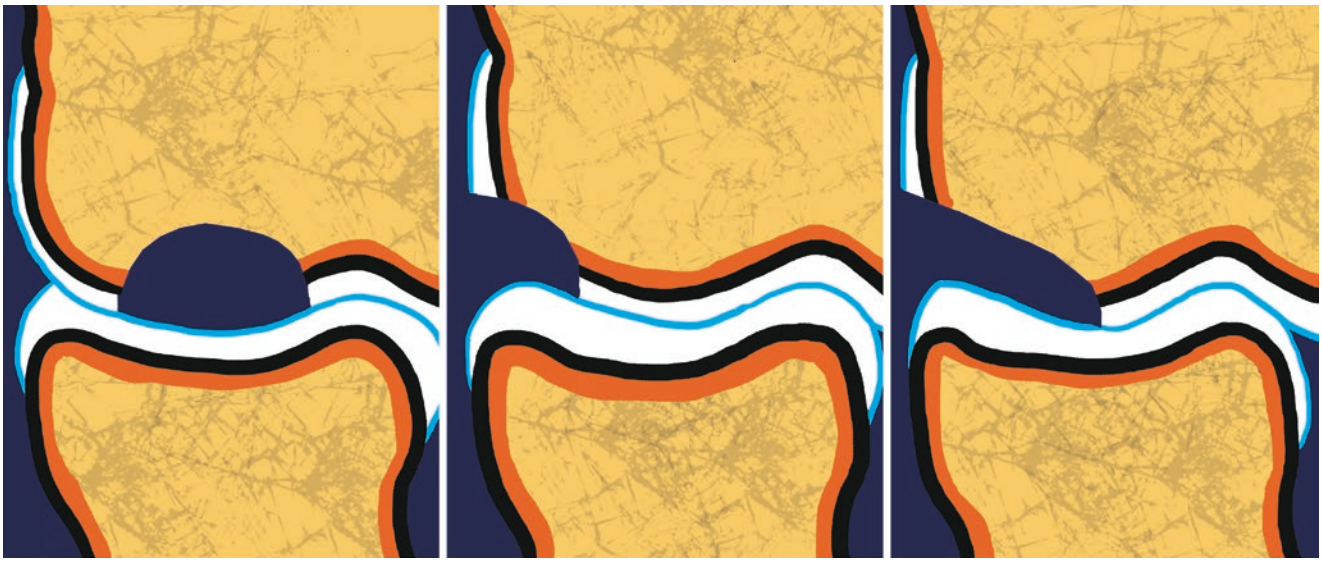


Fig. 35.2 Kosaka classification of capitellar OCD

subsequently modified by the ICRS (International Cartilage Repair Society) (Brittberg and Winalski 2003) and developed as the following:

- Group 1: stable lesions with intact and smooth but soft cartilage
- Group 2: stable lesions with partial discontinuity but stable when probed (cartilage fibrillation or fissuration)
- Group 3: lesions with complete discontinuity but without dislocation (osteochondral fragment free but not displaced)
- Group 4: lesions with empty defect and displaced osteochondral fragment (loose body)

35.7 Therapeutic Management

Treatment of elbow OCD is very controversial because the potential healing process and the natural history of injuries are still poorly understood (Ruchelsman et al. 2010; Pappas 1981; Bradley and Petrie 2001; Takahara et al. 2007). Several authors (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Takahara et al. 2007; Mihara et al. 2009) agree that the management of OCD lesions should be based mainly on the integrity and stability of the cartilage surface. In the early stages of OCD (Takahara stable lesions, Bradley-Petrie stable grades IA and IB), in absence of clinical signs and symptoms of instability (joint locks, locking, clicking), conservative treatment is to be considered the best option; it is a modification of the activities with the cessation of participation in sport (Ruchelsman et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Takahara et al. 2007; Mihara et al. 2009). The modification of the activities with the elimination of all the stress is maintained from 3 to 6 weeks, while sport resume cannot be performed before 6 months (Ruchelsman et al. 2010; Bradley and Petrie 2001; Takahara et al. 2007; Mihara et al. 2009). In the early stages the treatment can also benefit from drugs and braces. Stretching exercises and progressive muscle strengthening can be started after the pain has disappeared. During this time the subchondral bone should fully recover and stabilize the lesion, thereby giving the right support to the overlying cartilage. In this early stage, X-rays are not suitable to assess the healing of the lesion and take decisions on return to sports. Recently, many authors have stressed the importance of an open physis in OCD healing with conservative treatment (Takahara et al. 2007; Mihara et al. 2009).

Surgical treatment is to be reserved to all cases of unstable lesions, for the presence of hypointense signal on T2 MRI, loose bodies, mechanical signs and symptoms, or stable lesions that have not benefited of at least 6 months of conservative therapy (Bradley and Petrie 2001).

Takahara et al. (2007) clearly indicated a surgical treatment for all injuries except stable lesions with open physis. Several controversies exist regarding the choice of the appropriate surgical management (Ruchelsman et al. 2010; Nissen 2014; Baker et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Takahara et al. 2007). The choice has to be targeted to the stimulation of healing and the elimination of mechanical symptoms by taking into account the size, depth, and location of the lesion. Various surgical options have been described, both open and arthroscopic, and include the removal of loose bodies with or without debridement, abrasion, drilling, microfracture, fixation of the fragment with

different techniques and devices, bone grafting, osteotomy, or osteochondral autograft transplantation (OAT).

35.8 Review of Literature

A clear review of the literature is challenging for several reasons: studies often do not distinguish the different stages of the disease, the classifications used are very different, and not all studies include MRI evaluations. Surgical techniques have changed over the years, and it may be inappropriate to compare recent with older studies. Following it is reported a brief overview of the literature, which takes into account studies considered important in terms of surgical techniques and outcomes.

35.8.1 Conservative Treatment

Recent studies support the use of conservative therapy in the early stages of the disease. Takahara et al. (2007) report that whereas good healing can be achieved in patient with stable lesions, radiographic grade I, and normal range of motion with open physis, no improvement can be achieved in patient with unstable lesions, radiographic grade II or III, or closed physis.

Mihara et al. (2009) evaluated 39 baseball players with capitellar OCD. Thirty of these patients, who were in the early stage of the disease (grade I or IIA of the Iwase's classification (Iwase and Igata 1988)), were treated conservatively. At a mean follow-up of 14.4 months, 25 patients showed radiographic signs of healing. Moreover, 16 out of 17 patients with open physes had resolution of symptoms, compared with only 11 of the 22 patients with closed physes.

Matsuura et al. (2008) treated conservatively 101 patients with capitellar OCD at radiographic stages I and II. Noticeably, 90.5% of patients with stage I lesions recovered elbow joint function in an average period of 14.9 months, while only 52.5% of stage II patients were healed in an average period of 12.3 months.

35.8.2 Surgical Treatment

35.8.2.1 Arthroscopic Debridement, Fragment Excision, and Marrow Stimulation

Medium- and short-term follow-up studies have shown that arthroscopic debridement, fragment excision, and marrow stimulation can be highly successful in terms of symptoms resolution and return to sports.

Baumgarten et al. (1998) have treated 16 patients with capitellar OCD with arthroscopic removal of loose bodies and with abrasion chondroplasty. At a mean follow-up of 48 months, four patients still reported elbow pain. Fourteen patients had returned to sports and played at the same level as in the previous year, and eight patients at X-ray follow-up showed a flattening of the capitellum in the absence of osteoarthritis.

In another study, Byrd and Jones (2002) examined ten young baseball players treated arthroscopically, seven of whom had grade 4 or 5 disease according to Baumgarten classification. Surgical treatment consisted of synovectomy, chondroplasty, shaving, and removal of loose bodies, if present. At a mean 4 years follow-up, four patients had returned to professional baseball (all four had high-grade lesions), and only two showed radiographic degenerative changes.

Miyake and Masatomi (2011) retrospectively reviewed 106 patients treated with arthroscopic debridement. At a mean follow-up of 13 months, 84% of patients had no pain. However, radiographic and clinical results were poor in patients with larger lesions and open physis of the proximal radius.

Unfortunately, in some studies with longer follow-up, inferior outcomes are reported. Brownlow et al. (2006) retrospectively reviewed 29 patients treated with arthroscopic debridement. At a mean follow-up of 6 years, although clinical results were good, 38% of patients still reported elbow catching and more than half still complained pain. Six out of 18 patients showed radiographic degenerative changes and five still had loose bodies.

Ruch et al. (1998) treated 12 patients with unstable lesions. At a mean follow-up of more than 3 years, mechanical symptoms were resolved in 11 patients. However, only three patients had returned to sports, and six showed degenerative changes of the radial head. In this series the size of the lesion did not correlate with improved postoperative symptoms.

As for the knee and talus, arthroscopic microfractures can be performed to stimulate the release of multipotent bone marrow cells and fill the defect with a hyaline-like fibrocartilage tissue.

Wulf et al. (2012) evaluated ten patients with III–IV ICRS grade lesions who were treated with arthroscopic microfractures. The lesions had an average size of 98.2 mm^2 (range 50–180 mm^2). At a mean clinical follow-up of 42 months, all patients reported significant improvements, and eight had returned to play sports at pre-injury competitive level after an average of 5.1 months. At a mean follow-up of 27 months, radiological MRI images showed a normal or nearly normal signal intensity. Seven patients showed an irregular profile of the subchondral bone and eight had a cartilage-like tissue that filled the defect perfectly.

Bojanic et al. (2006) reported on the short-term outcomes of three elite gymnasts treated in the same way for the presence of advanced lesions. All three athletes reported having

returned to their competitive activity, and their postoperative MRI showed that the defect was completely filled with hyaline-like tissue.

35.8.3 Fixation of the Fragment

Fragment fixation can be done with many techniques, open or arthroscopic, and using different types of devices including Herbert screws, dynamic staples, pullout wiring, pins, bioabsorbable implants, and bone fixation pegs (Ruchelsman et al. 2010; Yadao et al. 2004; Bradley and Petrie 2001; Takahara et al. 2007; Harada et al. 2002; Takaeda et al. 2002; Kuwahata and Inoue 1998; Nobuta et al. 2008).

In the literature, although positive results for the treatment of advanced lesions have been reported in small series of capitellar OCD, many authors have expressed doubts about the real healing capability of the fragments (Bradley and Petrie 2001).

Harada et al. (2002) evaluated fragment fixation in four patients with dynamic staples inserted unicortically with the support of a graft obtained from the iliac crest. At 7.5 years follow-up, the authors reported a union rate of 100%, and all patients had no pain and a full range of motion. Three of them had returned to play competitive baseball.

Takaeda et al. (2002) used fragment fixation with pullout wire and bone graft from proximal ulna in the management of 11 patients. At 17 weeks X-rays showed bone union and wires were removed. At a mean follow-up of 57 months, ten patients had an excellent result with a full return to sports. Only minimal degenerative changes were present in three elbows.

Takahara et al. (2007) has also reported better results in patients after fragment fixation or reconstruction of the articular surface compared to those treated with only the fragment removal.

Similarly, Kuwahata and Inoue (1998) successfully treated seven patients with fragment fixation using Herbert screws and cancellous bone grafts. At an average of 32 months, all patients returned to sports.

Nobuta et al. (2008) reported their experience with 28 patients treated with drilling and fragment fixation using a double wiring technique through a lateral arthrotomy. Complete resolution of pain was achieved in 25 patients. Radiographic healing was obtained only in 11 patients, partial healing in 12 patients, and no healing at all in three patients. Two patients developed loose bodies, while wire breakage was reported in three patients at the time of their removal.

Uchida et al. (2015) chose to treat 18 teenage baseball players through arthroscopic fragment fixation using hydroxyapatite/poly-L-lactic acid (HA/PLLA) thread pins. At a mean follow-up of 39 months, the clinical and functional results were excellent. Fifteen patients had returned to previous or even greater competitive levels. Only two patients played at a lower level, while only one patient did not return to play baseball.

35.8.4 Osteochondral Autograft Transplantation (OAT)

OAT has been introduced in the treatment of this disease following its successful outcomes in the treatment of osteochondral lesions of the knee. This surgical technique is performed by placing in the lesion one or multiple osteochondral cylinders (mosaicplasty) harvested from a donor site (unloaded areas of the knee or sternocostal joints). In our opinion candidates for this procedure are the patients with large defects (>1 cm^2) or defects affecting the lateral wall of the capitellum.

Iwasaki et al. (2009), who performed this technique by taking 3.5 mm cylinders from the peripheral part of the lateral condyle of the knee, showed good to excellent results in 18 out of 19 male athletes at a median follow-up of 45 months. Seventeen patients had returned to pre-injury competitive levels, whereas only one patient reported problems at the donor site.

Shimada et al. (2005) reported on ten OCD patients treated with mosaicplasty. In this study, eight patients achieved excellent results while only two did not. The poor outcome in these two patients was attributed to the location of the defect that had hindered a good fixation of the plugs.

Muryama et al. (2014) treated 33 patients with autologous osteochondral transplantation, harvesting osteochondral cylinders (diameter, about 7 mm) from the lateral condyle of the knee. The average size of the treated lesion was 16 × 14 mm (coronal x sagittal). At a folllow-up time of 28.4 months, 30 patients had no pain, and all except two had returned to their previous competitive levels. One patient complained donor site morbidity, experiencing anterior knee pain during exercise.

Other authors (Yamamoto et al. 2006; Ansah et al. 2007) have also shown encouraging short- and medium-term results. However, some complications have been reported. Although a recent report (Iwasaki et al. 2007) shows no adverse effects on the donor site upon plug removal from the knee, other authors (Iwasaki et al. 2009; Muryama et al. 2014) have described problems related to the donor site after mosaicplasty. Another disadvantage of this procedure is the fragility of the graft, especially when it is placed in the lateral defect of the capitellum (Shimada et al. 2005). Furthermore, doubts remain about the different cartilage curvature and thickness of the donor site.

In recent years some surgeons, to overcome some of these drawbacks, have begun to use the rib as a donor site.

Shimada et al. (2012) treated 26 patients using the 5° rib as the donor site. At a median follow-up of 36 months, the clinical and functional results, as well as graft assessment, were very positive, as evidenced by radiographic and MRI results. In particular, MRI examination at 12 months revealed several outcomes: ten patients showed a homogeneous hyperintense signal in T1,suggesting complete revascularization; 13 patients showed a mixed hypo-hyperintense signal, suggesting ongoing remodeling. At 12 months T2 images showed a congruent joint line in 20 patients, but only 13 patients maintained the same congruent joint line at the next follow-up. Finally five patients required additional minor surgical procedures.

Nishinaka et al. (2014) published a series of 22 young athletes treated with the same technique. At a median follow-up of 27 months, all patients had returned to their pre-injury competitive levels. Only four patients required minor surgery, such as removal of screws and loose bodies.

35.9 Authors' Preferred Management and Surgical Technique

For elbow OCD, the therapeutic choice depends on clinical symptoms (presence of mechanical symptoms, range of motion limitation), radiographic and MRI images, as well as patients' competitive levels and functional request. In the presence of stable lesions and in the absence of mechanical symptoms, the first treatment is a 6-month conservative treatment. However, when after this period the symptoms persist, we consider the surgical option. Surgical treatment is also necessary in the presence of unstable lesions, lesions associated with mechanical symptoms, and loose bodies. In lesions <1 cm^2 treatment of choice is arthroscopic debridement with the possible removal of loose bodies, synovectomy, capsulectomy, and microfractures. In lesions >1 cm^2 or in lesions in the lateral side of the capitellum, the treatments of choice can be autologous osteochondral transplantation from the rib, bone marrow-derived cells transplantation with scaffold, or arthroscopic mosaicoplasty from the knee.

35.9.1 Osteochondral Autograft Transplantation (OAT) from the Rib

The surgical technique is performed as follows (Fig. 35.3a–v):

Anesthesia is usually mixed, with general procedure and peripheral block. The patient is in supine position with a pneumatic tourniquet at the limb's root.

A standard lateral approach to the elbow is performed with exposition of the lesion. Loose bodies are removed, if present. Then a debridement and curettage of the lesion is performed until a regular cylindrical groove is created (Fig. 35.3g–j).

Then through a small incision in the transverse sulcus of the breast, a 15 mm in height osteochondral cylinder is removed from 5° rib (Fig. 35.3 m,n) with COR® precision targeting system (DePuy Synthes—Mytek Sports Medicine, Raynham, MA, USA) and inserted into the sulcus of the lesion (wedge technique) (Fig. 35.3 o-p). A standard closure is then performed as usual.

35.9.2 Bone Marrow-Derived Cells Transplantation with Scaffold

Recent acquisitions in the field of regenerative medicine demonstrated that mesenchymal stem cells (MSCs) are able to replicate and regenerate bone as well as cartilaginous tissue, therefore without any need for a laboratory treatment (Galois et al. 2005; Oreffo et al. 2005; Bashir et al. 2014; Giannini et al. 2009).

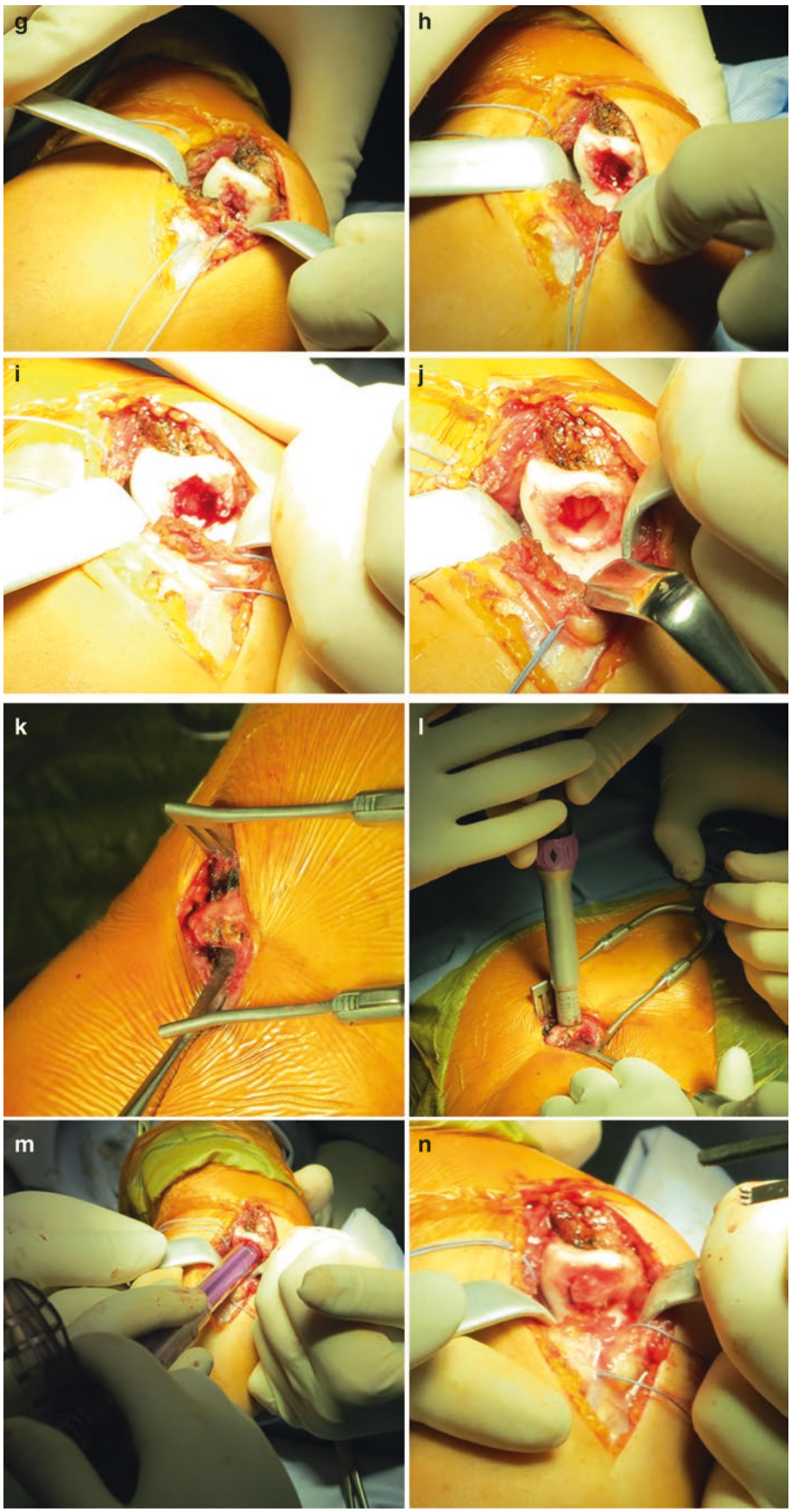
The differentiation of MSCs into different lineages, such as osteoblasts and chondrocytes, can be influenced on site by mechanical stimulation and growth factors. The role of the surrounding bone marrow microenvironment is also a key factor, since the properties of a multipotent cell are no longer to be considered only an intrinsic capability of the cell itself but also the interaction between a cell with its physiologic niche that provides a signaling network (Lucarelli et al. 2003; Bosnakovski et al. 2006; Dominici et al. 2004; Kacena et al. 2006; Olmsted-Davis et al. 2003; Taichman 2005). In fact, adhesion molecules, extracellular matrix, growth factor, cytokines, and chemokines secreted by the resident cell, along with MSCs, are believed to be necessary for bone and cartilage regeneration (Dominici et al. 2004; Kacena et al. 2006; Olmsted-Davis et al. 2003; Taichman 2005).

The bone marrow-derived cells transplantation (BMDCT) in fact aims to transfer into the lesion site the whole high regenerative potential present in the bone marrow by the implant of MSC together with the mononuclear cells (Dominici et al. 2004; Kacena et al. 2006; Olmsted-Davis et al. 2003). Furthermore the bone marrow contains not only stem cells and precursor cells but also accessory cells that support angiogenesis by producing several growth factors (Dominici et al. 2004; Kacena et al. 2006; Olmsted-Davis et al. 2003). This ability can be particularly helpful in the treatment of osteochondritis dissecans, where the possibility to regenerate the subchondral bone is strictly dependent on angiogenesis which is not so brilliant as evidenced by the etiology of the disease. Following this rationale, our aim was to implant into the defect the entire regenerative potential of the bone marrow niche, without the need to select and expand the MSC in a lab phase all in a rapid and less expensive one-step procedure. This technique, originally developed for



Fig. 35.3 (**a**–**d**) Case report: CT scan of a 14-year-old professional gymnast. (**e,f)** Preoperative X-ray. (**g**–**j**) Osteochondral autograft transplantation (OAT) from the rib: preparation of the lesion. (**k**–**n**) Removal of the osteochondral cylinder from 5° rib. (**m**,**n**) Insertion of the graft into the sulcus of the lesion (**o**–**p**). (**o–r)** X-ray at 45 days follow-up. (**q**–**r**) MRI at 12 months follow-up: coronal GE STIR (**s**) and axial TSE T2 (**t**). (**s–v**) Clinical evaluation at 12 months follow-up (**s**–**u**); scar in the area of the 5 rib (**v**)

Fig. 35.3 (continued)



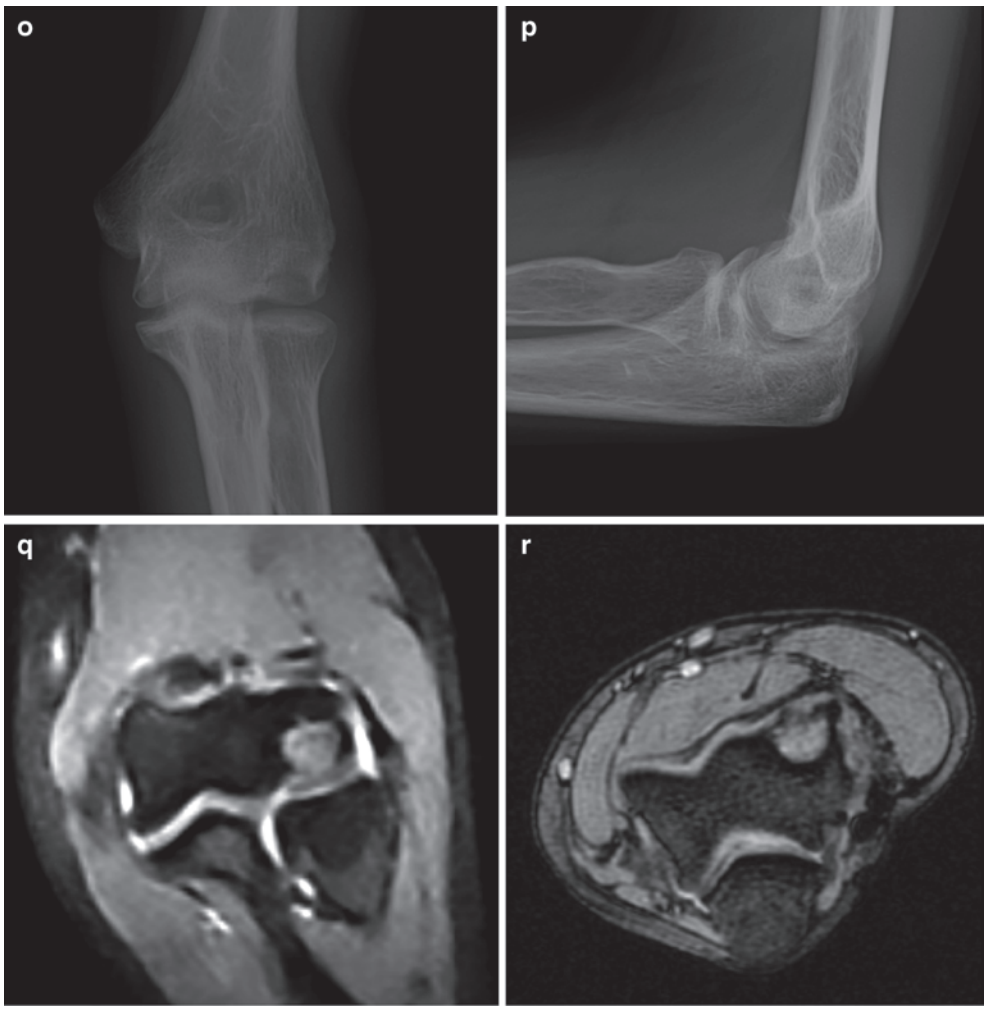


Fig. 35.3 (continued)

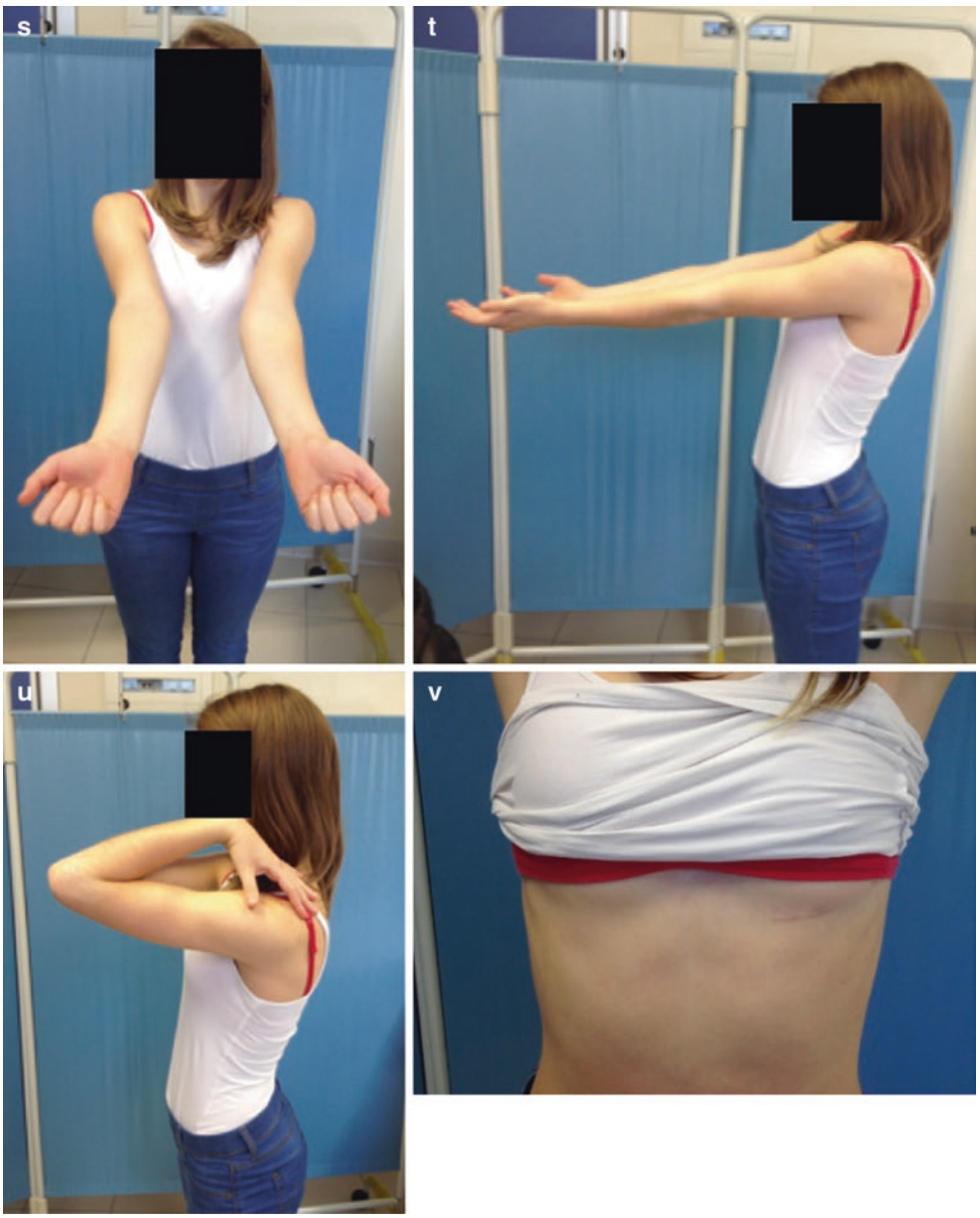


Fig. 35.3 (continued)

osteochondral lesions of the ankle, reported also excellent results for osteochondritis dissecans of the knee (Dominici et al. 2004; Kacena et al. 2006; Olmsted-Davis et al. 2003; Taichman 2005; Giannini et al. 2010; Vannini et al. 2012).

35.9.2.1 Surgical Technique

The surgical technique for the BMDCT consists of several phases, all to be performed during the same surgical session.

35.9.2.2 Platelet-Rich Fibrin Gel Production

Platelet-rich fibrin (PRF) is the richest in fibrin and is able to coagulate faster than regular PRP, providing so that, an additional stability of the implant due to early clot formation.

The PRF is produced with an automatic system the day before the operation or the same day. One hundred twenty ml of venous blood is harvested and processed with the Vivostat system (Vivolution A/S, 3460 Birkeroed, Denmark) obtaining 6 ml of PRF.

35.9.2.3 Bone Marrow Aspiration

The bone marrow is aspirated from the posterior superior iliac crest after preparation of a sterile surgical field with the patient lying prone and already under spinal or general anesthesia. This location is preferable to the anterior iliac crest because of the higher number of available cells (Pierini et al. 2013). The equipment for the bone marrow harvesting, concentration, and implant comes with the dedicated kit IOR-G1 for osteochondral regeneration (Novagenit, Mezzolombardo, Trento, IT, Fig. 35.4). It is also possible to perform the bone marrow harvesting in lateral decubitus position that is to prefer when the treatment is performed arthroscopically with the same decubitus (Fig. 35.5).



Fig. 35.4 Kit IORG1 for one-step osteochondral regeneration (Novagenit, Mezzolombardo, TN). This kit is composed by all the disposable instruments for bone marrow aspiration and concentration and the bioabsorbable collagen scaffold for the marrow concentrate positioning onto the lesion site



Fig. 35.5 Bone marrow aspiration. The bone marrow to be concentrated can be aspirate from posterior or anterior iliac crest, with the patient in prone or lateral decubitus. We prefer the posterior iliac crest for the higher number of mesenchymal stem cells, and the patient in lateral decubitus ready for the following phase of the surgical procedure

By insertion of the needle size 11G to a depth of 3 cm in the iliac crest, a total of 60 ml of bone marrow is harvested as a result of subsequent aspirations and placed in a bag preloaded with 500 U of heparin in 10 ml of saline solution. The whole bone marrow volume is then reduced by eliminating the plasma and the red cells, thereby increasing its stem cell concentration. This procedure is performed in the surgical theater using a cells separator-concentrator (Res-Q, ThermoGenesis, Rancho Cordova, CA) and its related sterile and disposable kit. After a 15-minute working cycle, 6 ml of concentrated cells are obtained.

35.9.2.4 Surgical Procedure

The procedure is performed firstly with an elbow arthroscopy (Fig. 35.6) in order to perform a whole articular balance and lesion visualization, localization, and a confirmation of the indication for the procedure. The arthroscopic step is useful also to identify the best open approach to perform the following step according to the lesion's localization.

In order to better perform the biomaterial implant, we prefer to convert the arthroscopy into a mini-open procedure: the two portals (mediolateral and posterolateral) are conjuncted by a skin incision, and the capsule is approached and



Fig. 35.6 Patient positioning. The patient is positioned in lateral decubitus, with the elbow at 90° on a proper arm holder, and the procedure is performed arthroscopically in its first part

(Fig. 35.7). The biomaterial is positioned into the lesion site directly in open procedure (Fig.35.8b) or by sliding it to the edge of the lesion with the help of a special windowed cannula. A flat probe then helps to perfect the implant position. In order to provide a growth factor supplement and to further improve the stability of the implant, the PRF is applied to cover the lesion with the dedicated spray pen (Fig.35.8c). The implant stability is checked with multiple elbow flexions and extensions, a gravity drainage is positioned in the anterior chamber, and proper closure is performed.

In the postoperative the elbow can be progressively mobilized in flexion and extension from the first day after the surgery, with restriction on weight lifting for the first 2 months. In case of lateral ligament detachment, a brace is advised for the first 2 weeks in order to protect the ligament reconstruction.

The lesion site progressed with the regenerative process over time, with the formation of a regenerate tissue with the aspect of bone in the inferior portion covered by cartilaginous tissue in the site previously affected by osteochondritis dissecans (Figs. 35.9, 35.10, and 35.11).

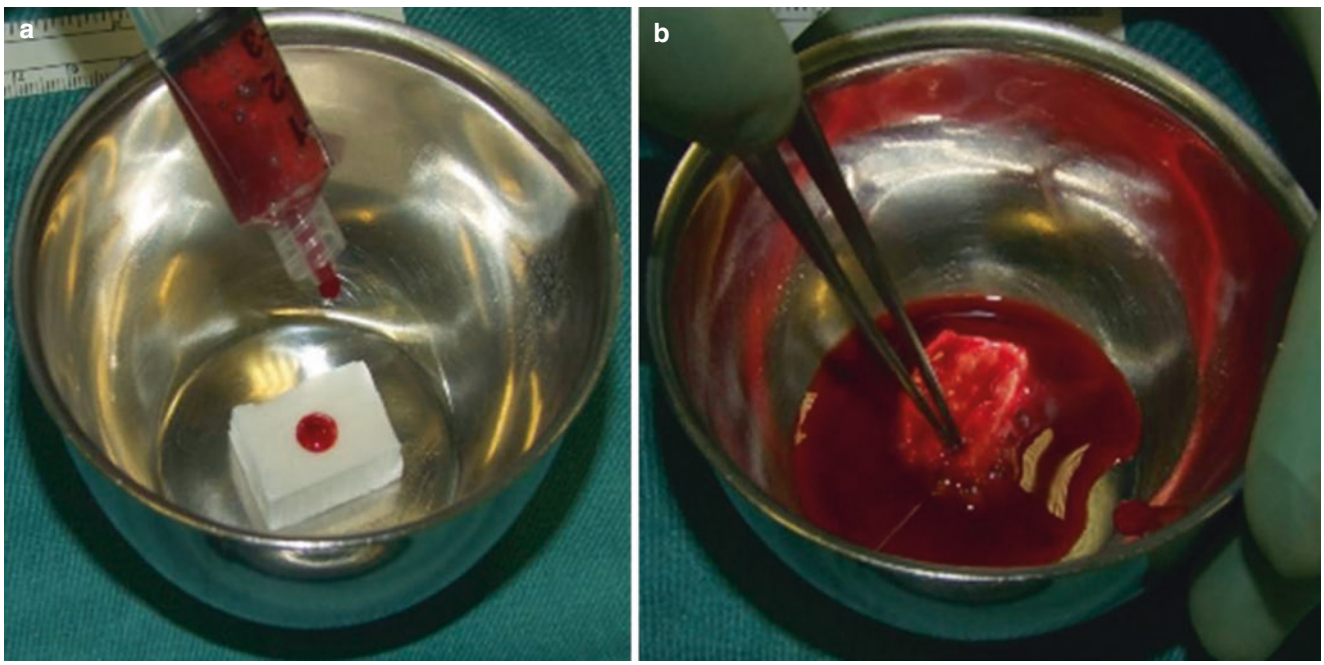


Fig. 35.7 The collagen membrane is loaded with 2 ml of bone marrow concentrate (**a**), which is fully absorbed in approximately 2 minutes (**b**)

sectioned in the interval between anconeus and extensor ulnaris carpi. The osteochondral fragment is detected and removed, with subchondral damaged bone shaving. The size of the lesion is measured (Fig. 35.8a), and the biomaterial to be implanted is then cut accordingly.

The collagen membrane within the kit is used for cell support. Approximately 2 ml of marrow concentrate are loaded on the highly hydrophilic membrane and rapidly absorbed

35.9.3 Arthroscopic Mosaicplasty from the Knee

When performing arthroscopic mosaicplasty, our preference is to arthroscopically harvest the graft from the omolateral knee.

Anesthetist identifies nerve trunks by applying electrostimulation and places a catheter without injecting the anesthetic. Patients then undergo general anesthesia. Peripheral

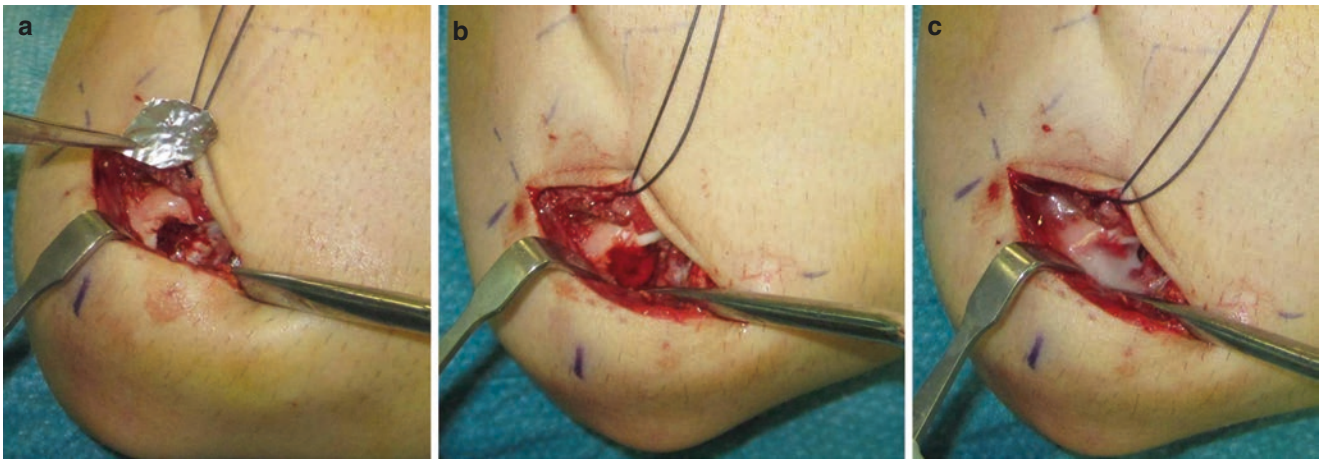


Fig. 35.8 The last phase of the surgical procedure is performed by open procedure: the lesion size is measured with the possible help of an aluminum layer (**a**), the membrane filled with bone marrow concentrate is positioned onto the lesion site (**b**), and finally a layer of platelet gel (PRF) is sprayed on top to help the stability of the biomaterial and to provide further growth factors (**c**)

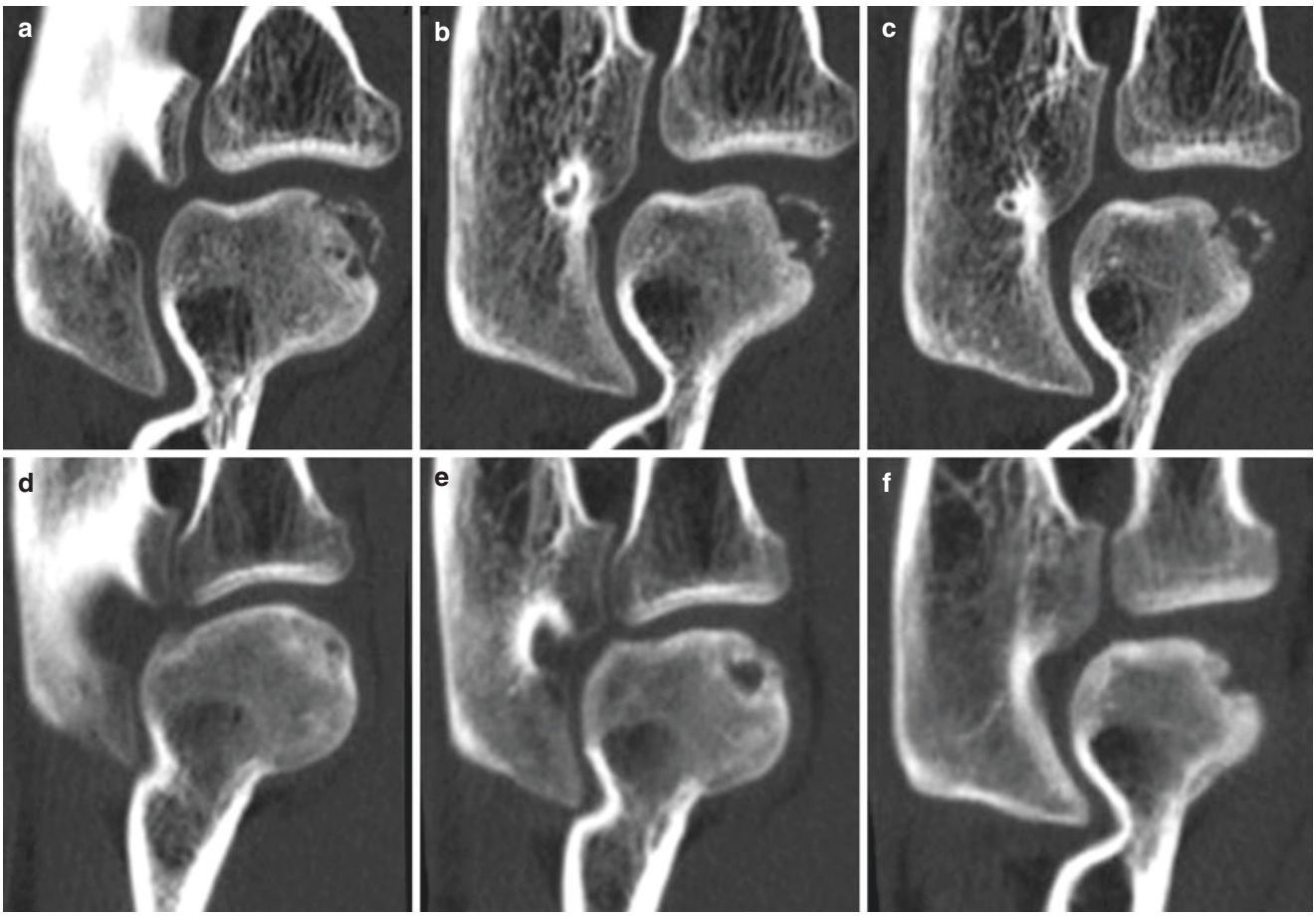


Fig. 35.9 (**a**–**c**) Preoperative CT scan showing the area of OCD. (**d**–**f**) The same area at 2 years of follow-up: a regeneration of the bony layer is evident, even if a small spot of non-ossified subchondral bone is present

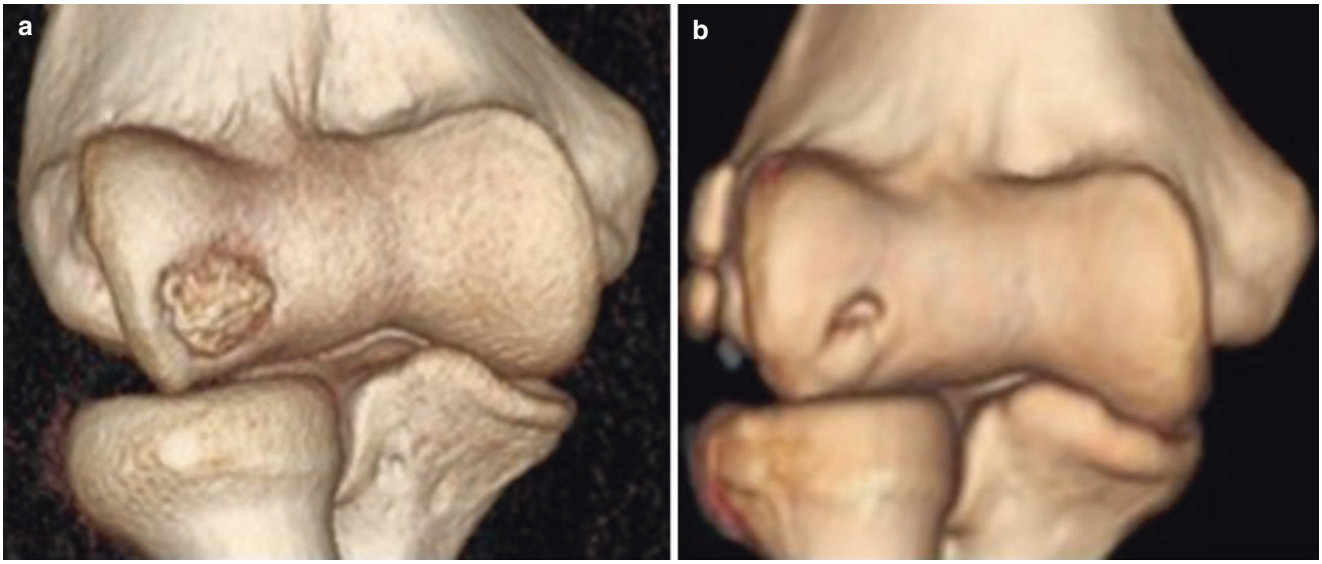


Fig. 35.10 3D CT scan preoperatively (**a**) and at 2 years of follow-up (**b**)

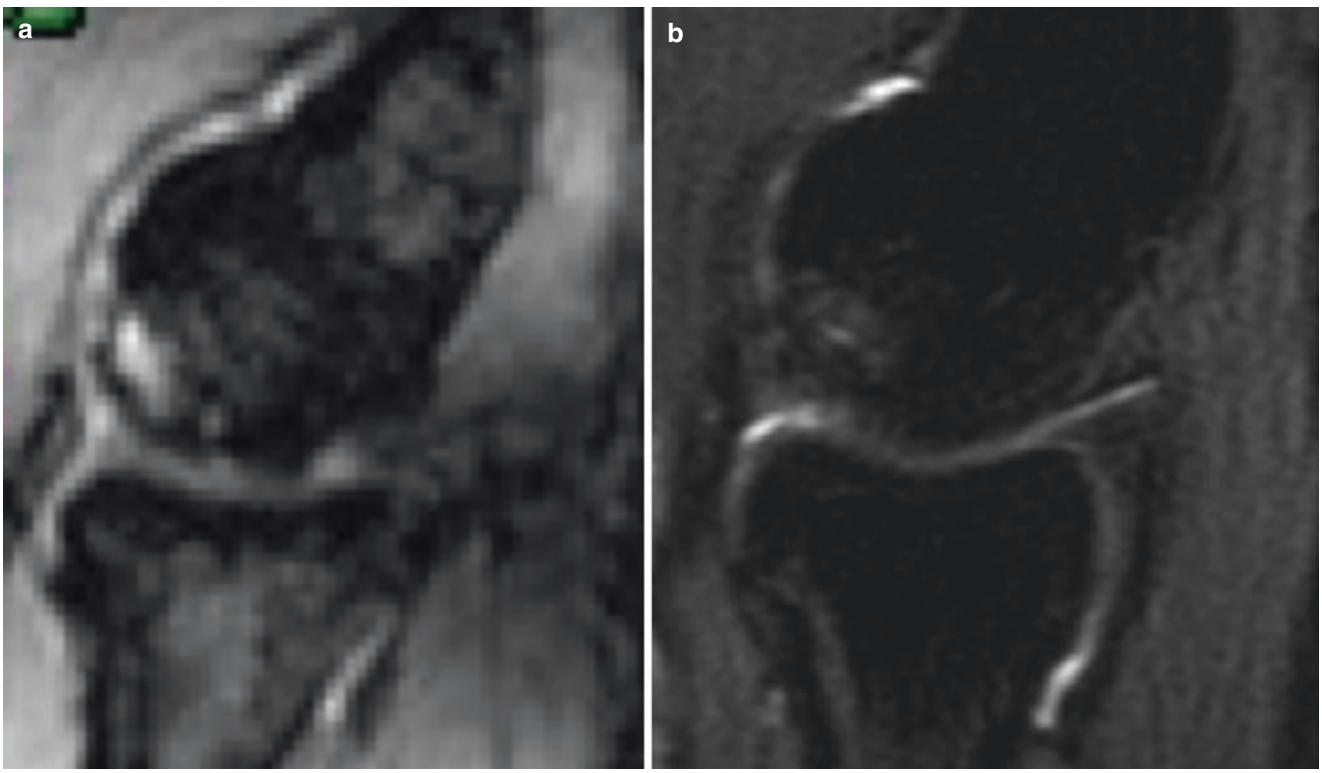


Fig. 35.11 MRI showing the OCD of the capitulum humeri (**a**) and the good defect filling at 2 years of follow-up (**b**)

block is performed after surgery, when the patient wakes up, and a careful neurologic assessment can be carried out.

The patient is then placed in lateral decubitus extrarotating the hip, in order to perform knee arthroscopy for graft harvesting. The shoulder is abducted 90°; the elbow is flexed 90° and the arm held up by an arm holder secured to the operating table (Fig. 35.12).

The tourniquet is then inflated to 250 mmHg.

An 18-gage needle is inserted in the elbow through the "soft spot," in the middle of the triangular area delimited by the epicondyle, the radial head, and the olecranon, and the joint is distended by injecting 20 ml of N-saline solution. Five portals, three posterior and two anterior, are generally used.



Fig. 35.12 The patient is placed in lateral decubitus with extrarotated hip to perform knee arthroscopy. The shoulder is abducted 90°; the elbow is flexed 90° and the arm held up by an arm holder secured to the operating table

Posterior compartment arthroscopy is firstly performed by introducing a 4,5 mm 30° arthroscope through the posterolateral portal (soft spot). Then a second portal is established, 1,5 cm proximal to the latter. These two portals allow the use of the scope and the shaver at the same level of the posterior portion of the radial head.

Joint distension is achieved by a pump set at 35–50 mmHg. Once we get a good and complete view of the proximal radio-ulnar joint (posterior view), a third posterior portal is placed in the olecranon fossa, close to the triceps medial border and oriented 2–3 cm proximal to the olecranon tip.

Two posterior-lateral portals in the posterior soft spot of the elbow allow to identify the OCD and prepare the lesion for insertion of the osteochondral graft.

The osteochondral cylinder is harvested from omolateral knee from the non-weight-bearing area of the proximal aspect of the lateral femoral condyle arthroscopically (Figs. 35.13, 35.14, and 35.15).

The 6.5 mm osteochondral graft is pressed fit in the prepared OCD, carefully checking the drilling and insertion angle. The insertion of the graft allows a complete coverage of the OCD area. The cylinder press fit positioning technique makes the graft stable. [Fig. 35.16, and 35.17].

When the OCD lesion lies in the anterior aspect of the capitellum, the arthroscopic procedure is technically too demanding, and open surgery is recommended.

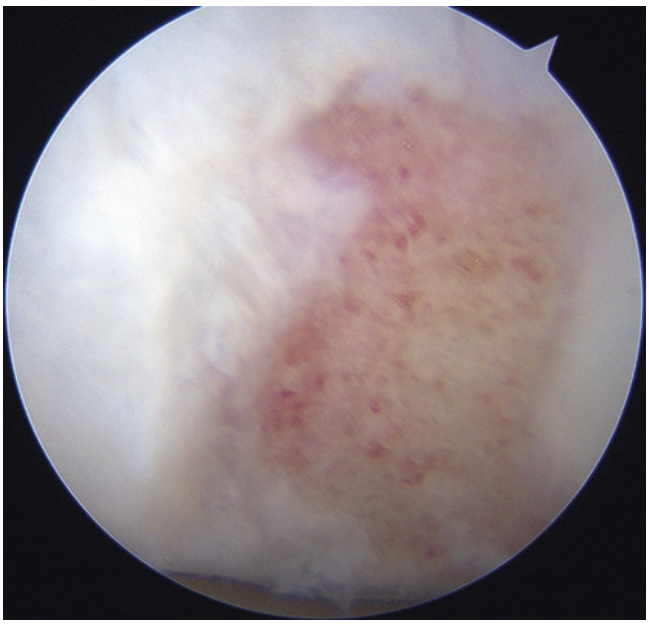


Fig. 35.13 Arthroscopic view of OCD of the capitulum humeri

Usually at the 4 months follow-up MRI, the bone incorporation of the graft is evident with this technique. Patients are able to return to their normal activity in 4 months.

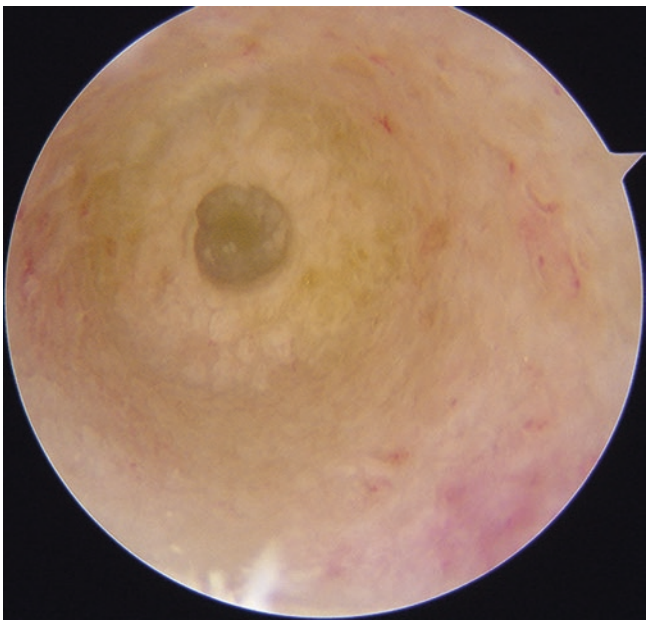


Fig. 35.14 Arthroscopic view of the prepared OCD area

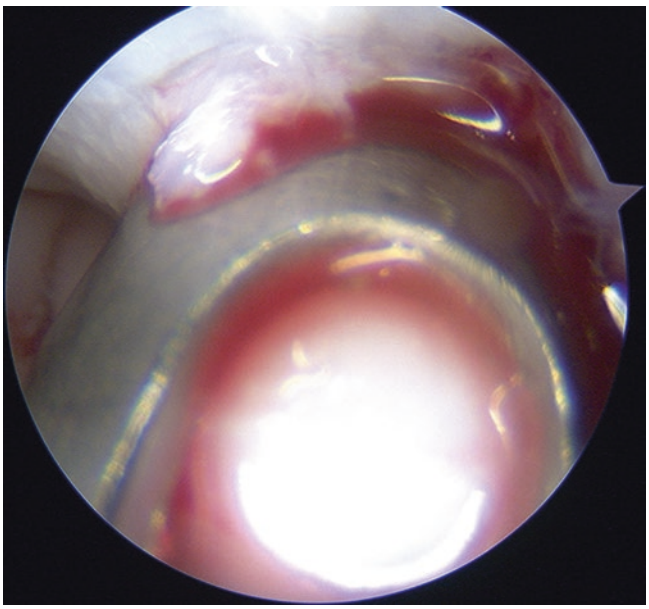


Fig. 35.16 The graft is press fit into the prepared OCD



Fig. 35.15 The graft harvested from lateral, non-weight-bearing part of the patellofemoral joint by use of properly sized tubular chisels

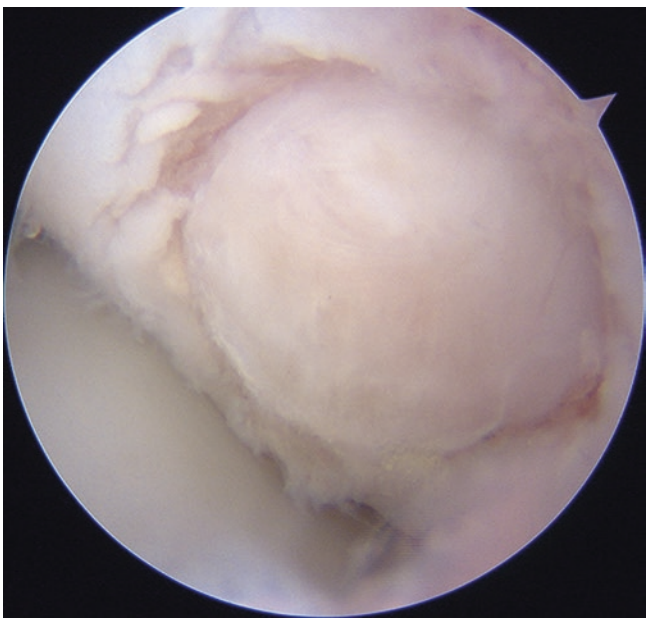


Fig. 35.17 Final view of the graft inserted in the prepared OCD lesion

Conclusions

Osteochondritis dissecans of the capitellum are occurrences that often affect young people practicing sports activities, limiting their daily life and sport activities with pain and symptoms like locking, cracklings, and swelling. To date the advancement of the diagnostic tools usually

allow a clear detection and classification of the lesion, but the best treatment option is still to be identified. Conservative management is usually advised for stable lesions without additional symptoms, especially in skeletally immature patients, whereas in different condition, a surgical treatment is often necessary. In literature various surgical options are reported, with different advantages and drawbacks. The three surgical techniques described in this chapter represent the state of the art for the treatment of elbow OCD, having marked good results with minimal side effects. The choice of the preferred technique is demanded to the surgeon that must perform the surgery, after an accurate patient evaluation and balancing the specific advantages and possible side effects of the different procedures in that specific patient.

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Rehabilitation Plan After Elbow OCD Surgery

36

Silvia Di Giacomo

Osteochondritis dissecans (OCD) of the elbow is very common among young athletes aged between 10 and 17 years who are involved in overhead sports, such as baseball, and gymnastics (Dexel et al. 2014; Harding et al. 2011; Jobe and Nuber 1986; Kancherla et al. 2014).

In our clinical practice, usually we rehabilitate patients undergoing OCD surgery with osteochondral autologous transplantation (OAT) from the rib.

According to the technique used by Dr. Porcellini and his surgical team, immediately after surgery, patient wears a removable splint extended at 30° and flexed at 40° (Fig. 36.1).

Rehabilitation path begins 2 days after surgery as follows:

- Splint removal for therapeutic session and then immediately repositioned after work
- Slow and gradual passive flexion and extension of the elbow
- Passive flexion of the elbow up to 90°, without compression or traction to prevent any pressure on the transplant

Although little evidence is available on the effects of early postoperative mobilization, we believe that early mobilization is necessary to prevent tissue stiffness and to assure more effective rehabilitation outcomes of the operated elbow (Cain et al. 2003, Baugmarten et al. (1998), D'Angelo et al. (2014), Jobe (1998)).

Whether the patient undergoes two or three physiotherapeutic session a week will depend on the physiotherapist's perception of stiffness. However, if therapist feels that the elbow tissue is soft and the movement is free, two 30-min sessions will suffice.

Fifteen days after removal of stitches, physiotherapists do a scar massage program both at the elbow and at the graft site. And then the patient is instructed on how to perform a daily 3- to 5-min self massage. It is important to cover the scars in the summertime to prevent its abnormal pigmentation (see Figs. 36.2 and 36.3).



Fig. 36.1 Patient 3 days after osteochondral autologous transplantation (OAT) from the rib for capitellum OCD; 3D CT scan before surgery

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Fig. 36.2 3D CT scan before surgery of this patient



Fig. 36.3 Patient's scar after three months from surgery

Theoretically, during the early phases following surgery, it is crucial that patient recovers the full range of motion of the limb especially with respect to flexion and extension. A lack of such recovery could delay the complete limb upturn. In most patient, we observed that passive flexion was more resistant to movement than passive extension—a phenomenon likely due to the greater compression at the site of the humeral condyle. Such occurrence should not however be of major concern to physiotherapists, as there will be plenty of time ahead to regain extension flexion activity.

Indeed, during the first 2 months following surgery, the major objective is to obtain a relatively complete range of motion of the limb.

Pool therapy, to perform an active-assisted ROM and to start elbow strength recovery on all planes, can begin about 35 days after surgery.

The equipment used during these sessions is generally meant to build up muscular strength of the various muscle groups pertaining to the elbow and shoulder through concentric and eccentric resistance exercises. Patients should be trained to reproduce his sport-specific movement in the water. In case of gymnasts, these would entail open but also closed kinetic chain exercises (50 days from surgery).

At this time, it is necessary that the patient gradually regains strength in all scapular muscles too, because they stabilize and support the whole upper limb than allowing a coordinated and finalized gesture.

Together with the beginning of the shoulder muscle strengthening, the patient has to go on with passive mobilization exercises and to carry out home exercises to facilitate the upper body movement recovery.

In this regard, we recommend to perform an open kinetic chain resistance band exercises only after 80 days from surgery.

If exercises are painful, elbow tension can be decreased by placing the elastic band on the arm just above the elbow.

Forty-five days from surgery and after a radiographic checkup, the patient begins to perform natural weight-bearing exercises (Fig. 36.4).

Sixty days after surgery, the patient starts an active reinforcement initially targeted to the elbow and shoulder muscle groups. In this early strengthening phase, we try to help the patient using sectoral and targeted movements or by following the muscle movement chains.

Indeed, human movement is divided into two chains of movements which entail the combination of either flexion, internal rotation, and adduction, or extension, external rotation, and abduction (Figs. 36.5, 36.6, 36.7, 36.8, 36.9, 36.10, and 36.11):

Ninety days after surgery, the patient can begin weight- and load-bearing training. Since gymnastics place excessive strain on the elbow, a careful rehabilitation plan should be

laid out to allow a full return to their sport-specific activities. During this rehabilitation phase, the athlete begins bilateral upper arm loading activities by using his own natural body weight (Figs. 36.12, 36.13, and 36.14). CKC exercises are generally performed with loading destabilization for the lower limbs in order to develop proprioception. In addition to these exercises, patients carry out prone exercises for scapular muscle strengthening using gravity resistance (Figs. 36.15, 36.16, 36.17, and 36.18).

One hundred days after surgery and after medical clearance, the athlete can begin his gym workout mainly by lower limb strengthening exercises and by gymnastic routine training exercises.

At this time, we recommend the athlete to execute load-bearing propaedeutic exercises for the upper limbs and then progressively continue with the training toward a full support.

So, according to what is said, first, gymnastic exercises are ought to be those that entail no arm support.



Fig. 36.4 (**a**) Radiographic assessment viewed from anterior/posterior and lateral perspectives 45 days after surgery (**b**) patient showing passive elbow extension achieved 45 days after surgery

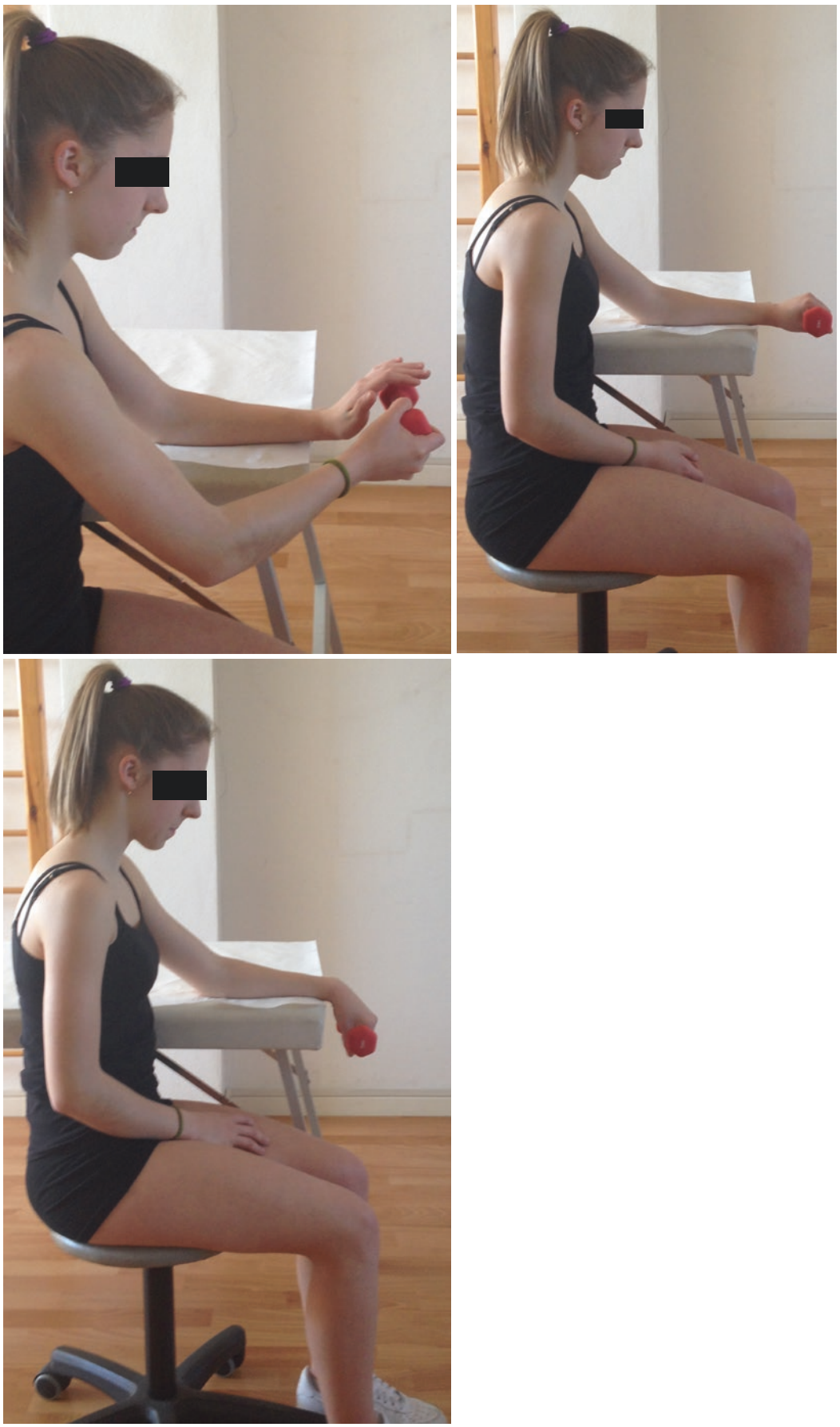


Fig. 36.5 Exercise sequence for eccentric contraction of epicondylar muscles

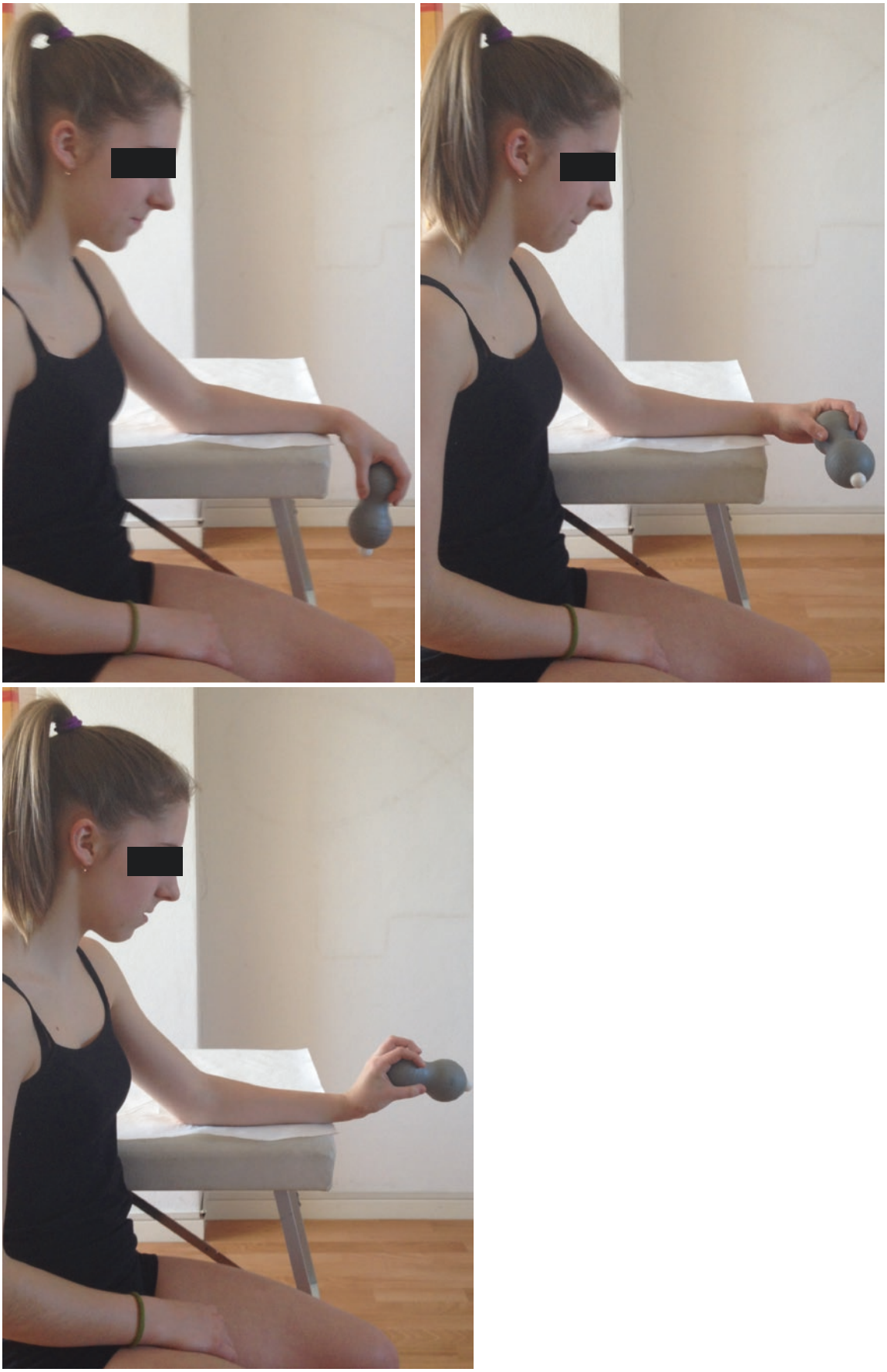


Fig. 36.6 Sequence of strengthening training exercises for muscles involved in supination and pronation of the hand and forearm

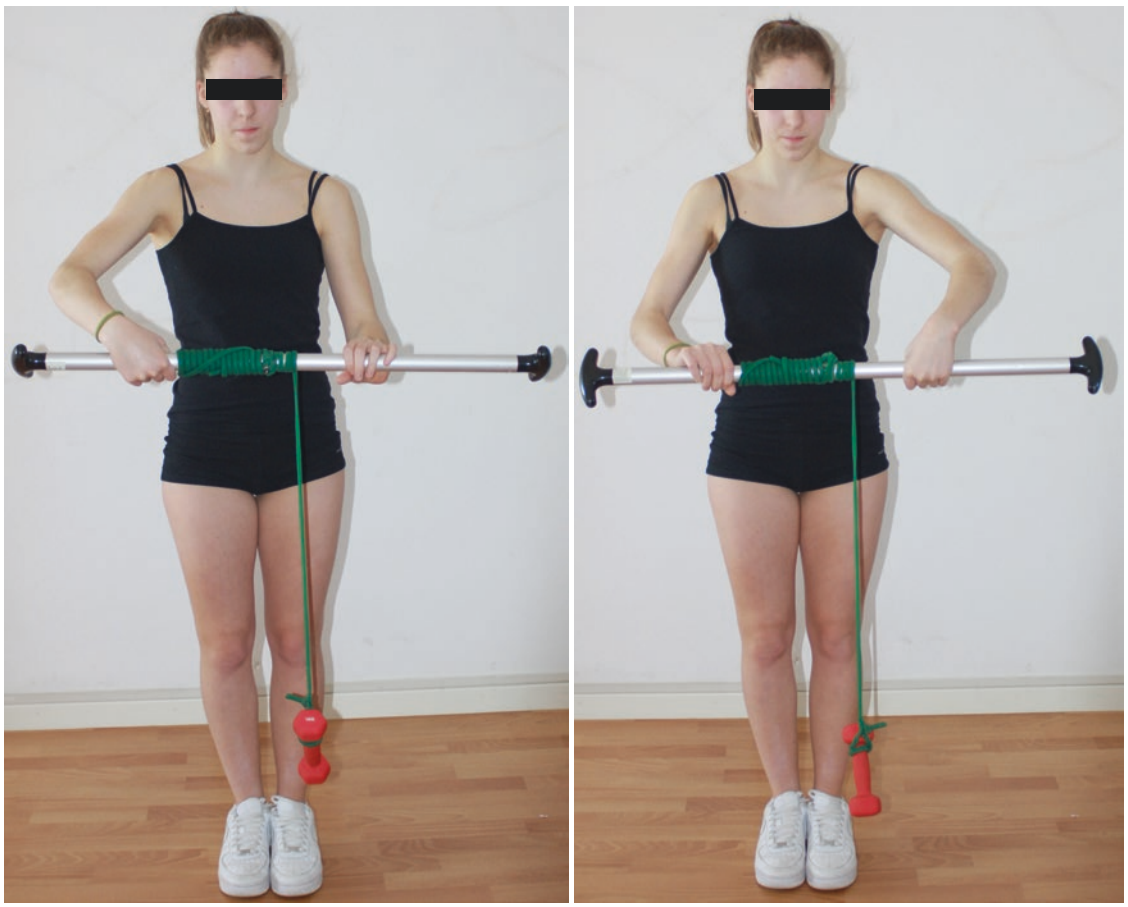


Fig. 36.7 Wrist flexion and extension training exercises 80 days after surgery



Fig. 36.8 Manipulation exercises



Fig. 36.9 Resistance band exercises from standing position to strengthen internal and external rotator muscles of the humeral head. This type of exercise facilitates fiber recruitment in external rotation through the contraction of chain movements in extension(extension/external rotation/abduction). These exercises are to be performed 80 days after surgery



Fig. 36.10 Specific strengthening exercises for subscapularis muscles through shortening of pectoralis (law of mechanical disadvantage)



Fig. 36.11 Open kinetic chain exercises of the upper limb according to Kabat's chain of movements. The exercises entail little resistance but great neuromuscular control



Fig. 36.12 Wall bar exercises from a standing position entailing loading activity with little body weight



Fig. 36.13 Series of exercises in which patient leans against a Bobath ball to facilitate proprioception



Fig. 36.14 Upper body push up exercises with vertical destabilization



Fig. 36.15 Sequence of upper limb load-bearing exercises from most simple to most complex



Fig. 36.16 Pushups on an unstable surface with legs extended or flexed



Fig. 36.17 Monopodalic loading on proprioception board in quadruped position

In this early stage of gym training, parallel bars should not be used because they require upper limb load-bearing support. Indeed, patients should be allowed to proceed to bar routines only toward the end of the rehabilitation period.

Literature states that return to the sport usually is possible about 7 months after surgery (Di Giacomo et al. 2013). Our recovery times agree with those of literature, and we believe that it is very useful for this purpose—a progressive rehabilitative gym training program already from third month after surgery (Table 36.1).

In this way, athletes will not lose their conditioning and will perceive as more natural—the ability to start reusing upper limbs.

What follows is a progressive rehabilitation plan that can be applied 100 days after surgery or during conservative treatment. Considering the high incidence of OCD in young



Fig. 36.18 Grip strengthening exercises on parallel bars and proprioception training with upper limb loading while patient stands on surfaces that exert different resistant forces

overhead athletes, we recommend that in case of persistent pain, a surgical and rehabilitation team should be consulted. Indeed, such specialized team would ensure a quick diagnosis and facilitate the athlete's return to full practice on the basis of a well-planned rehabilitation protocol aimed at preventing worsening of the pathology and symptoms (Kida et al. 2014; Maruyama et al. 2014; Mihara et al. 2009; Paterno et al. 2014; Wilk et al. 2012) (see Table 36.1).

Osteochondritis dissecans of the elbow

↓

Treatment guidelines for postoperative managment after elbow OAT

↓

Day 2: Passive elbow range of motion in flexion and extension and pronation/supination as tolerated

Day 15: removal of stitches and removal of splint

Day 35: Beginning of workouts in rehabilitative pool along with more elbow range of motion if necessary
Beginning of self-range of motion home exercises in flexion and extension

Day 60: Beginning of open kinetic chain exercises for scapula and elbow

Day 80: Beginning of resistance training through open kinetic chain exercises with elastic bands

Day 90: Beginning of resistance training through weight-bearing closed kinetic chain exercises

Day 100: Progressive load-bearing exercises for upper limbs;
Return to the gym for muscular conditioning of lower limbs;
Rehabilitation plan to regain the ability to work on all uneven bar routines without limb support

7 months: Return to sport specific training and competitive participation

Table 36.1 Gradual return to gymnastic training after OCD surgery or during conservative treatment

3 months after surgery				
1st and 2nd week	– Lower limb stretching – Jogging – Sit ups – Loosen up exercises (splits) – Loosen up exercises (rachis)	Shoulder and elbow exercises as described in rehab plan: elastic bands for both and specific elbow exercises		
3rd and 4th week	– Lower limb stretching – Jogging – Sit ups – Loosen up exercises (splits) – Loosen up exercises (rachis) – Sit ups	Shoulder and elbow exercises as described in rehab plan: elastic bands targeted elbow exercises	– Choreographic arm exercises – Gymnastic jumps on elastic jumping mat – Soft landing acrobatic jumps on elastic mat	
4 months after surgery				
	– Lower limb stretching – Jogging – Sit ups – Loosen up exercises (splits) – Loosen up exercises (rachis) – Sit ups	Shoulder and elbow exercises as described in rehab plan: targeted elbow exercises with elastic band	– Choreographic arm exercises – Gymnastic jumps on elastic jumping mat – Soft landing acrobatic jumps on elastic mat	– Choreographic floor exercises – Beam exercises – Floor and beam flips – Beam acrobatics without hand support: cartwheel and side somersault – Forward and backward flips
6 months after surgery				
After medical clearance and shoulder isometric test	– Gradual loading of hands – Gentle thrusts – Assisted handstand	– Front flips with hand support – Cartwheel with hand support	– Gradual floor push-ups – Assisted pullups	– Roundoff – Swings on parallel bars
9 months after surgery				
	Kippe parallel	Assisted vertical leaps at the parallel bar		
10 months after surgery				
	– Vaulting at the parallel bars – Swinging from lower to higher parallel	All gymnastic routines	Floor exercises: – All choreographic routines – All acrobatic routines except for flick flack	Backward flip with light thrust

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The Elbow in Wheelchair and Paralympic Athlete

37

Domenico Creta and Antonio Zucchini

37.1 Biomechanics, Propulsion, and Wheelchair Configuration

There are more than three million wheelchair users in the USA and 90% of them use manual wheelchair propulsion as their primary method of mobility (Kaye et al. 2000). A range between 30 and 73% of disabled people using wheelchairs complains of pain, which is three times higher than that of the general population, and reports injuries from wear and tear in the upper limbs with the shoulder that is the most commonly affected area followed by the wrist and elbow (Arnet et al. 2012; Lin et al. 2009; Dellabiancia et al. 2013).

The main pathologies that are correlated with the high physical demand placed on the upper extremity during wheelchair propulsion include subacromial impingement, long head of the biceps tendonitis, glenohumeral osteoarthritis, and injuries of the rotator cuff, the wrist, the elbow, and the hand (Lin et al. 2009; Dellabiancia et al. 2013; Arnet et al. 2012). These pathologies can be extremely debilitating and lead to a decrease in independence and quality of life (Gutierrez et al. 2007) and are due to overuse, muscle fatigue, and high loads that occur during the pushing phase and to the low mechanical efficiency of the device related to the difficulties of the patients to impart a perfectly tangential force to the wheel (Dellabiancia et al. 2013) since there is a limited range of motion due to confined wheelchair configuration (Lin et al. 2009). The mechanical efficiency of wheelchair propulsion ranges from 2 to 11%, and the applied force during wheelchair propulsion is shown to be biomechanically imperfect and ineffective, but physiologically it seems to be an advantageous and optimal solution (Lin et al. 2009). A seated wheelchair user holding the handrim has some freedom regarding shoulder position, elbow mediolateral position, and wrist angle, but the range of postural freedom is small, and limited user workspace critically affects propulsion efficiency and joint loading. The user automatically adopts an elbow position that feels easiest to generate force by himself, but this position may be or not the most efficient position for propulsion (Lin et al. 2009).

During a repetitive motion, biomechanical variables show a cyclic behavior so we can distinguish two phases in the propulsion: pushing and recovery (Dellabiancia et al. 2013). During the first phase, the hands partially follow the circular motion, and the wheel can be moved imparting a tangential force upward with the elbow flexed (between the beginning and the middle of the push) and one downward with the elbow extended (from the middle to the end of the movement) (Figs. 37.1, 37.2, and 37.3) (Dellabiancia et al. 2013). Although the greatest loads occur on the shoulder articulation, a further contribution of push is exerted by the wrist; as a result, the gradual change of the tangential force applied to the wheel has a detrimental effect on the rotator cuff. The combination of shear and compressive forces allows efficient abduction by stabilizing the humeral head within the glenoid fossa. The magnitude and direction of the resultant joint reaction force is dependent on the position of the arm; at 90° of abduction, the joint reaction force is at its maximum and equates approximately the weight of the body; during propulsion, the shoulder is maintained at approximately 70° of abduction (Dellabiancia et al. 2013). At the onset of the propulsive phase of motion, the shoulder is extended and internally rotated and subsequently ends up flexed and externally rotated at the onset of the recovery phase (Dellabiancia et al. 2013). As a result of years of wheelchair propulsion, wheelchair users often have well-developed shoul-

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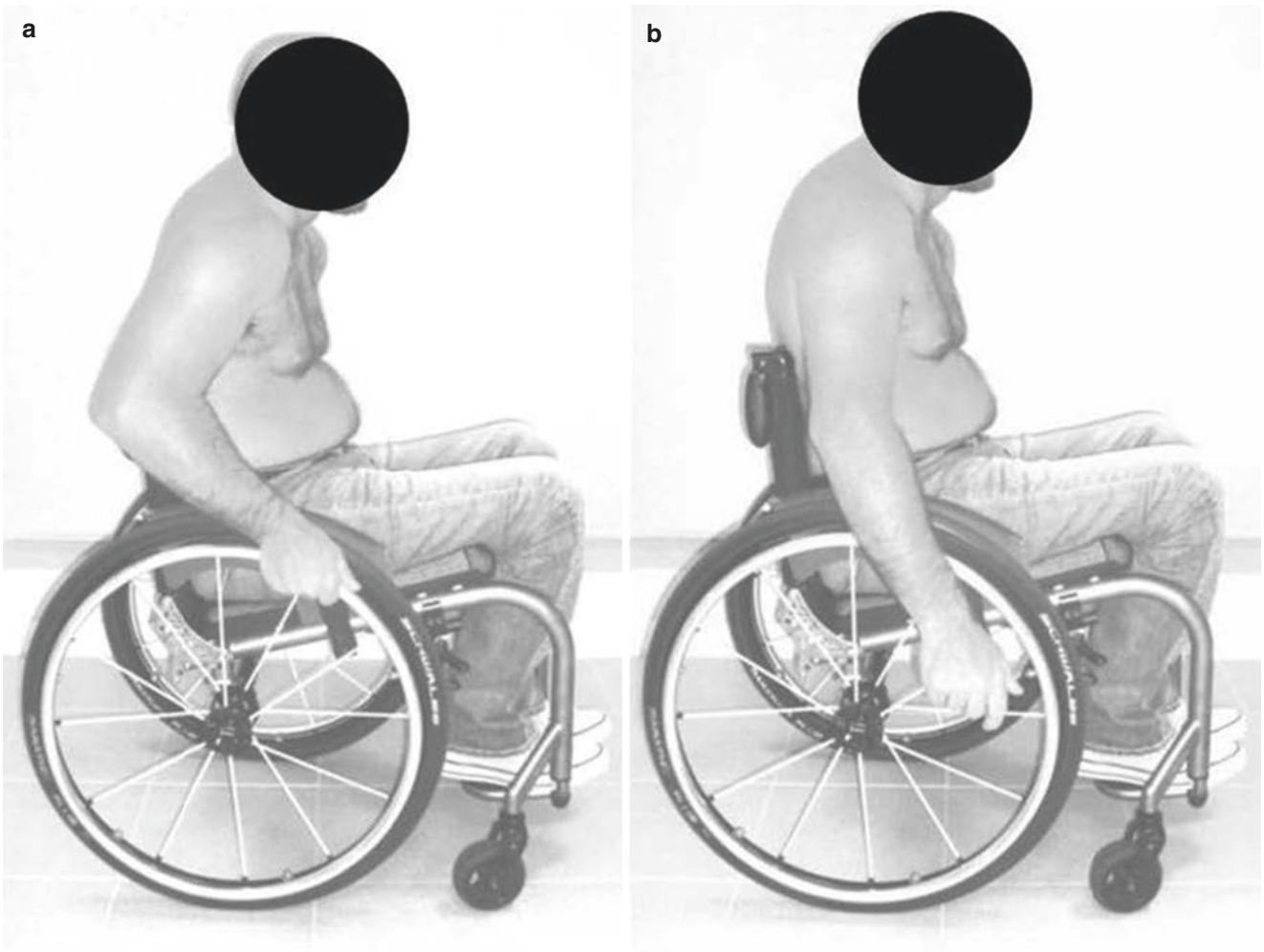


Fig. 37.1 Wheelchair propulsion: push (**a**) and recovery (**b**) phase. Reprint with permission of the Publisher, CIC Edizioni Internazionali S.r.l., MLTJ (Muscle, Ligaments and Tendons Journal), 2013; 3 (3): 150–156. Dellabiancia F, Porcellini G, Merolla G. Instruments and techniques for the analysis of wheelchair propulsion and upper extremity involvement in patients with spinal cord injuries: current concept review

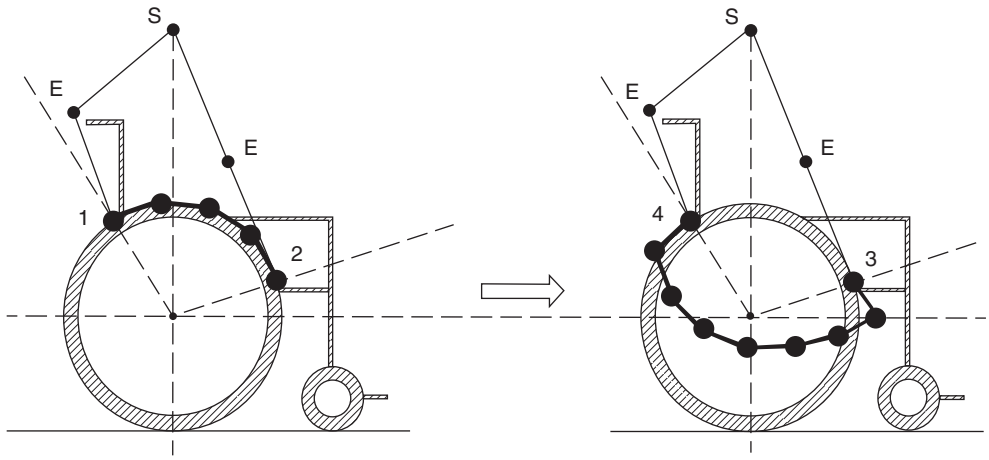


Fig. 37.2 Trajectory of the hands during the two phases of propulsion. *S* shoulder, *E* elbow, *1* start push, *2* end push, *3* start recovery, *4* end recovery. Reprint with permission of the Publisher, CIC Edizioni Internazionali S.r.l., MLTJ (Muscle, Ligaments and Tendons Journal), 2013; 3 (3): 150–156. Dellabiancia F, Porcellini G, Merolla G. Instruments and techniques for the analysis of wheelchair propulsion and upper extremity involvement in patients with spinal cord injuries: current concept review

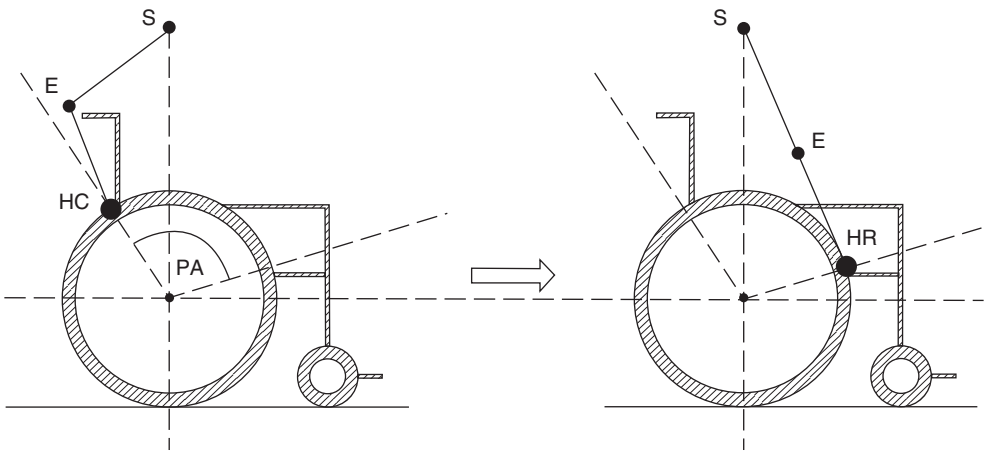


Fig. 37.3 Sagittal view of the wheelchair propulsion and technique parameters. *S* shoulder, *E* elbow, *HC* hand contact, *PA* push angle, *HR* hand release. Reprint with permission of the Publisher, CIC Edizioni Internazionali S.r.l., MLTJ (Muscle, Ligaments and Tendons Journal), 2013; 3 (3): 150–156. Dellabiancia F, Porcellini G, Merolla G. Instruments and techniques for the analysis of wheelchair propulsion and upper extremity involvement in patients with spinal cord injuries: current concept review

der flexors, internal rotators, and adductors, but may have poorly developed external rotators and thoracoscapular muscles; this muscular imbalance and the repetitive nature of the wheelchair push predispose to the subacromial impingement (Dellabiancia et al. 2013). The elbow is flexed throughout the pushing phase, starting from an angle of about 60°, gradually increasing until the hand assumes the most distant position from the ground, and subsequently decreasing until reaching the minimum distance from the ground near the recovery phase (Fig. 37.3) (Dellabiancia et al. 2013). The anterior deltoid, pectoralis major, and biceps brachii act primarily during the pushing phase, and contraction starts toward the end of the recovery phase with load peaks at around 10% of the pushing phase; conversely, the activity of the triceps brachii is initially quite modest during this phase, and then it gradually increases until the time of the release of the hand (Dellabiancia et al. 2013). The deactivation occurs in the final pushing phase, where the muscles of the recovery phase begin to act: middle and posterior deltoid, subscapularis, supraspinatus, and medium trapezius (Dellabiancia et al. 2013). Muscle fatigue can be monitored by electromyography, and it is defined as a change of the signal following a sustained contraction in time that precedes the inability to protract the effort required. The peak of muscular activity of the biceps brachii was found at hand contact, while triceps brachii increased progressively during the push phase, reaching maximal values at hand release (Dellabiancia et al. 2013). The highest joint moment found at the elbow was in flexion and peak flexion moments occurred at 10% of the propulsive cycle, and with regard to the ergonomics of the wheelchair, the seat tilted backward confers greater stability, and increasing the seat height, the activities of biceps brachii and pectoralis major decrease (Dellabiancia et al. 2013). The elbow joint is in a propulsion configuration in the first 10% of the propulsive cycle; from 11% to the end of the propulsive cycle, the elbow joint was found to be in a stabilization configuration (Dellabiancia et al. 2013). Flexion, internal rotation, and abduction were, respectively, the highest moments found at the shoulder joint. Peak flexion moment was revealed at 19% of the propulsive cycle, peak internal rotation moment at 21%, and peak abduction at 48%, and during the entire push phase, the shoulder joint reveals mainly a propulsion configuration (Dellabiancia et al. 2013). Near the end of the push phase (40% propulsive cycle), the joint shifts from a propulsion to a stabilization configuration. All handrim biomechanics (contact angle, peak force, average force, and peak axle moment) were found to be similar and highly correlated (Dellabiancia et al. 2013).

A lower seat position is significantly correlated with shoulder torque and reduced intensity of muscle activation during propulsion (Lin et al. 2009). Wheelchair seat position is an easily adjustable parameter that can influence the propulsion mechanics and the mechanical loads (muscle stress, co-contraction, and metabolic cost) generated on the upper extremity (Slowik et al. 2013). To reduce upper limb injuries, seat height should be positioned as high as possible without endangering user anteroposterior and/or lateral stability (Gorce et al. 2012), and using an anterior axle position configurations allows a greater manageability and simplifies two-wheel equilibrium (Brubaker 1986). High seat position could be considered less traumatizing for upper limb joints decreasing joint amplitude and muscle recruitment (Werner and Plancher 1998; Gorce et al. 2012); posterior settings are generally used for persons in institution or by paraplegic persons who need important anteroposterior stability (Gorce et al. 2012). Kotajarvi et al. (2004) indicated that average peak radial and axial force components significantly increased in lower seat positions, and Richter (2001) showed that as the seat height decreased, the shoulder torque decreased and elbow extension torque increased (Lin et al. 2009). This implied that the increased shoulder abduction in

the lower seat position might result in more radial and axial force components, which are not major components to drive the wheel forward (Lin et al. 2009). During wheelchair propulsion, the hand of the wheelchair user must follow the trajectory of the handrim, which results in limited range of motion of the upper extremity, and even if the distance between the shoulder joint and the wheel axis remain constant, changing upper arm orientation might alter joint torques and affect the preferred position (Lin et al. 2009). In previous research, higher pressure in the carpal tunnel was observed in wrist extension than that in flexion (Lin et al. 2009), but when the elbow is located at the inner position, wrist joint is flexed and ulnarly deviated. During wheelchair propulsion, users need to grip the handrim to apply forces, and maximal finger forces during forceful grip is produced at 20° of wrist extension and 51° of ulnar deviation; when the wrist joint is moved away from this position, there is a reduction in grip forces generated (Lin et al. 2009). Trend of changes in handrim forces can be seen in the effects of seat position, and when the elbow joint is located at the inner position, more flexed wrist joint was not appropriate to generate grip force on the handrim (Lin et al. 2009). Wheelchair users can propel a wheelchair only with their bodies held at positions which are biomechanically feasible to avoid high load on the wrist joint during propulsion (Lin et al. 2009). Further, users will propel a wheelchair at positions which are perceived to be optimally comfortable, efficient, and stress-free, but the literature suggests that these perceived positions may not provide optimal comfort, efficiency, and freedom from stress, and it is necessary to understand the relation of reachable workspace, hand position, and spontaneous elbow positioning that may assist improved wheelchair design, such as seat height, wheel width, and handrim diameter (Lin et al. 2009). Active experts' paraplegic patients mostly use semicircular or single-looping over propulsion patterns that have a two-phase propulsion pattern; a traction phase with radial deviation of the wrist at handrim contact followed by a push of the wheel and the median height (47 cm) is the one allowing the better handrim access (Gorce et al. 2012). The optimal seat position should minimize upper extremity demand and reduce the risk of pain and injury, and general results found over several studies include increased RF effectiveness (smaller radial force component), decreased peak forces, and increased metabolic cost as elbow angle is decreased from 100–120° to 70–90° (Munaretto et al. 2013). In effect as shoulder/axle distance decreases (via decreasing elbow angle and increasing forearm angle), RF directions which minimize elbow and shoulder NJM shift more toward the tangential direction, and increased force effectiveness tends to occur at lower positions (Munaretto et al. 2013). The increases in energy consumption found in experimental findings may be explained by issues with grip/frictional force. Generation of large frictional forces without normal forces requires strong muscular contraction, and metabolic costs may increase due to inability to efficiently generate tangential forces which is not feasible in many wheelchair users (Munaretto et al. 2013). For these reasons recent clinical guidelines suggest that seat position should be adjusted as far posterior as possible without compromising wheelchair stability (PVACSCM 2005; Slowik et al. 2013). The guidelines recommend superior/inferior positions that correspond to an elbow angle between 100° and 120° when the hand is at the top-dead-center (TDC) position on the handrim (full extension is 180°) (PVACSCM 2005; Slowik et al. 2013) since biomechanical efficiency is maximized and upper extremity demand is minimized at superior/inferior seat positions between 100° and 120° TDC elbow angles (Van der Woude et al. 2001), and a more recent study expanded that range to include 130° (Van der Woude et al. 2001; Slowik et al. 2013). Deviations from this seat position lead to increased metabolic cost, muscle stress, and co-contraction to maintain a stable, smooth propulsive stroke, which consequentially increases upper extremity demand, and this occurred despite the improvements in push angles and cadences that accompanied more inferior positions and the favorable reductions in joint ranges of motion that accompanied more superior positions (Slowik et al. 2013) (Fig. 37.4).



Fig. 37.4 Biomechanical efficiency is maximized and upper extremity demand is minimized at superior/inferior seat positions between 100° and 120° TDC elbow angles

37.2 Weight-Relief Lifts and Transfers

Wheelchair users must use their upper extremities for almost all activities of daily living (ADLs) such as getting in and out of bed; transferring to a toilet seat, a tub/shower bench, a treatment table, or a car seat; and vice versa (Tsai et al. 2014), and a full-time wheelchair user will perform on average 14–18 transfers per day (Gagnon et al. 2008). Transfers are a key element of living an active and productive life and play a vital role in maintaining independence of wheeled mobility device users, and if wheelchair users cannot transfer freely, their quality of life and community participation will be severely affected (Tsai et al. 2014).

37.3 Weight-Relief Lifts

Clinical practice guidelines recommend performing routinely by individuals with SCI weight-relief lifts (WRL) every 15–30 min of sitting and supporting body weight off the seat for at least 30 s for a period of about 2 min to bring the tissue oxygen level back to an unloaded level (Gagnon et al. 2008). During weight-relief lifts in a wheelchair in individuals with paraplegia, high (>50% EMGmax) to moderate (25–50% EMGmax) muscular demands of the latissimus dorsi, sternal pectoralis major, and long head of the triceps have been documented, especially during the lift phase, and a mean peak shoulder and elbow flexor moments of 0.6 and 0.5 N m/kg, respectively, were reported (Gagnon et al. 2008). During weight-relief lifts, shoulder and elbow peak absolute resultant moments were found to be more than five and nine times greater, respectively, compared with level manual wheelchair propulsion (Gagnon et al. 2008). When performing weight-relief lifts in a seated position, individuals with SCI generally place both hands on the arm rests or on the top part of the tires/handrims of the wheelchair, slightly in front of the hip joints in a symmetrical position (Gagnon et al. 2008). Thereafter, most individuals slightly bend their head and trunk forward while flexing and adducting their shoulders and extending their elbows at the same time to lift their body weight off the seat (Gagnon et al. 2008) (Fig. 37.5).



Fig. 37.5 Weight-relief lifts

37.4 Sitting Pivot Transfers

Transfers are a very intense wheelchair activities routinely performed by individuals with SCI, and sitting pivot transfers (SPTs) are the most mechanically challenging wheelchair-related activities, in shoulder and elbow joint forces and moments (Gagnon et al. 2008). About one half of wheelchair users do not learn how to perform correct transfer techniques or use transfer skills during rehabilitation (Tsai et al. 2014), and this situation may predispose wheelchair users to developing upper limb pain and overuse-related injuries, such as rotator cuff tears, elbow pain, and carpal tunnel syndrome (Tsai et al. 2014). During transfers there is a combination of shoulder flexion and adductor moments and large peak posterior and superior force at the shoulders that contributes to develop shoulder posterior instability, capsulitis, and tendonitis and increases the risk of shoulder impingement syndrome (Tsai et al. 2014). During transfers the elbow sustains high superior forces which may cause nerve compression and result in secondary elbow injuries (Tsai et al. 2014). When performing sitting pivot transfers, individuals with SCI generally place one hand beside the proximal half of the thigh slightly in front of the hip joint (trailing hand) on the initial surface, with the other hand positioned on the target surface (leading hand), far enough away to leave adequate space for the buttocks to land at the end of the transfer (Gagnon et al. 2008). From this position, they habitually flex and rotate the trunk and head forward and sideways while lifting the body off the initial surface and

pivoting the buttocks in one motion to the target surface. The sitting pivot transfers terminate when the buttocks land beside the leading hand on the target surface and sitting balance has been secured (Gagnon et al. 2008). During transfers, the shoulders often assumed a position of flexion, abduction, and internal rotation. This position brings the glenohumeral head in closer alignment to the undersurface of the acromion and has been identified as a critical risk factor for impinging subacromial soft tissue (Tsai et al. 2014). Off-loading the elbows and loading the shoulders more may make for a more efficient transfer particularly for individuals who lack elbow extension function (Tsai et al. 2014). Although triceps muscle function can make a transfer easier (assist with lifting the buttocks off the surface), it is not a primary mover in transfers (Tsai et al. 2014). The primary movers for transfers are the actions of the pectoralis major muscles, serratus anterior, and latissimus dorsi muscle groups which are all attached to shoulder (Tsai et al. 2014). The increasing extension shoulder moment may have resulted from the recruitment of the large primary movers, such as the latissimus dorsi and pectoralis major muscles which can drive the movement and shift the body weight during transfers (Tsai et al. 2014). When individuals with SCI perform sitting pivot transfers, higher muscular activation is measured during the lift phase of the transfer compared with the pre-and post-lift phases for the majority of UL muscles (Gagnon et al. 2008), and high (>50% EMGmax) to moderate (25–50% EMGmax) muscular demands have been reported at the serratus anterior, latissimus dorsi, supraspinatus, infraspinatus, pectoralis major, anterior deltoid, and long head of the biceps, and only low triceps activity (<25% EMGmax) has been found during sitting pivot transfers (Gagnon et al. 2008). In this study Gagnon (Gagnon et al. 2008) found the sustained substantial superiorly directed forces at the elbow were 3.57–3.95 N/kg across all conditions studied that were accompanied by anteroposterior and mediolateral joint forces of lower intensity (0.85–0.88 N/kg). The superiorly directed joint forces clearly dominated for the elbow joint forces and were found to be similar across the three distinct roles played by the dominant UL, and in the elbow this component strongly predominated the other directions (Gagnon et al. 2008). The considerable amount of superiorly directed joint forces compresses this joint and may explain some secondary musculoskeletal impairments like the compression neuropathy of the ulnar nerve (Gagnon et al. 2008). The anteroposterior and mediolateral force components may contribute to the development of other secondary impairments in patients with elbow instability. For the elbow moments, comparable extensor moments were generated across the different roles played by the dominant UL (Gagnon et al. 2008). The need for a flexor moment during sitting pivot transfers was confirmed and brings into question the clinical hypothesis that only an extensor moment is crucial when sitting pivot transfers are performed (Gagnon et al. 2008). This flexor moment at the elbow was found to be of greater importance when the UL acted as the leading UL rather than the trailing UL, which may confirm its pulling role during sitting pivot transfers as previously documented (Gagnon et al. 2008), and this finding partly confirms the results emerging from EMG studies revealing moderate biceps activation and low triceps activation during sitting pivot transfers and adds to the findings reporting negligible biceps activation during weight-relief lifts among individuals with paraplegia (Gagnon et al. 2008). Sitting pivot transfers and weight-relief lifts may expose the dominant shoulder joints to substantial posteriorly and superiorly directed forces, respectively, and the elbow was found to sustain elevated superiorly directed forces when these two tasks were performed (Gagnon et al. 2008). The shoulder flexor and adductor moments and the elbow flexor moments are also higher during sitting pivot transfers than during weight-relief lifts. The elbow extensor moments were similar when sitting pivot transfers or weight-relief lifts were performed (Gagnon et al. 2008). Prevention may be crucial to reducing upper limb pain and overuse injuries, and learning to transfer in a way that reduces forces and improper joint motions is an important strategy for preserving upper limb function (Tsai et al. 2014). It is necessary during the initial intensive rehabilitation process among individuals with SCI to develop task-specific strength training protocols to reach optimal shoulder strength before initiating transfer training and weight-relief lifts (Gagnon et al. 2008). During this period, the use of human assistance or a technical aid like a sliding board when individuals with SCI are performing sitting pivot transfers should be encouraged until these individuals reach sufficient strength-generating capability to potentially minimize UL mechanical loads (Gagnon et al. 2008). With proper use of both different transfer skills and transfer techniques that reduce upper limb joint forces and moments, it is possible to minimize the risks associated with secondary injuries and to prevent injuries (Tsai et al. 2014). For example, wheelchair users should angle their wheelchairs appropriately relative to the target surface (20–45° degrees) to reduce the large internal rotation shoulder moments on the leading side which can occur when using a proper leading handgrip (Tsai et al. 2014) (Fig. 37.6).



Fig. 37.6 (**a**–**f**) Sitting pivot transfers

37.5 Elbow Overuse

Tendons are force-transmitting units of the musculoskeletal system, and due to their low metabolic rate and slow healing, chronic overuse injury may cause structural changes and impact on tendons and peripheral soft tissues (Erhan et al. 2013). The elbow joint, together with the shoulder, serves as one of the main biomechanical units during the daily activities of paraplegic patients such as weight-relief lifting or transfers, and high-to-moderate muscular demands were documented on long head of triceps muscle besides latissimus dorsi and sternal pectoralis muscle during these activities (Erhan et al. 2013).

In this study Erhan et al. (2013) investigated the elbow joint with ultrasonographic evaluation in SCI patients and compared with healthy controls to found out the presence of fluid (humero-radial and humero-ulnar joints anteriorly and olecranon fossa posteriorly), to evaluate triceps tendon

thickness (TTT) or other pathologies of the elbow joint or the surrounding soft tissues like edema or bursitis. A total of 25 (83%) SCI patients were using manual wheelchair, and in these patients they found that TTT (right dominant side) values were larger in SCI patients (functional adaptation) when compared with those of healthy controls, right TTT was positively correlated with BMI, joint effusion (right dominant side) was found to be more common in SCI patients than normal subjects, and two patients with elbow pain had fluid in their both elbows (Erhan et al. 2013). Van Drongelen (2006) also has investigated the acute changes in the biceps tendon after a high-intensity wheelchair propulsion activity in 42 basketball and quad rugby players using ultrasonography; an increase in fluid content of biceps tendon was shown, which increased as the duration of playing time increased showing a link between activity level and acute tendon changes, and this association is probably more profound in high-intensity activities. Pain was present in 7 out of 30 (23%) of this small group of SCI patients (Erhan et al. 2013), and in another study Dalyan et al. (1999) found that the prevalence of pain was 35%. In other studies the prevalence of pain is reported as 6–15%, so we can confirm that elbow pain affects about 1 out of 4–6 patients, and it would be important to understand causes of pain and to use preventive measures to reduce pain and functional limitation (Erhan et al. 2013). Sie et al. (1992) reported elbow pain in 16% of manual wheelchair users and defined significant pain as that which required analgesia, occurred with two or more ADLs, or required cessation of activity. With this definition, the prevalence of all upper extremity pain complaints was 20% at 5 years post injury and 46% from 15 to 19 years post injury (Boninger et al. 1998). Hurd et al. (2008) examined the propulsion symmetry of individuals with paraplegia and noted that asymmetry is a function of wheeling surface, that pain limits activity, and that different terrains encountered in the day require different demands on the upper extremity and quantified the differences in elbow translation as a result of speed; right elbow anteroposterior translation was found to be significantly different during slow and fast and slow and normal speeds; vertical and mediolateral translation of the right elbow was significantly different between slow and fast speeds (Goins et al. 2011). During the initial phase of propulsion, the elbow goes from an extended position into greater flexion, and at the midpoint of propulsion, the elbow begins to extend until the end of the stroke. Two distinct patterns were seen during recovery; half of the subjects gradually flexed the arm during recovery in preparation for the next stroke, while the remainder of the subjects show a more rapid flexion followed by extension during recovery prior to initiating the next stroke, and for each subject, at both the shoulder and the elbow, the patterns seen during the stroke were regular and repeating across speeds (Boninger et al. 1998). During propulsion the minimum abduction angle was found to significantly decrease with speed, so it means that as the subjects propelled the wheelchair faster, they held their arms in a more adducted position, and for the entire stroke and both sagittal plane flexion/extension and elbow flexion/extension, ROM was found to increase with increasing speeds (Boninger et al. 1998). Sagittal plane flexion/extension ROM increased by approximately 8° and elbow flexion/extension ROM increased by approximately 4°, and peak acceleration during propulsion was found to increase in sagittal plane flexion/extension, abduction/adduction, and elbow flexion/extension. The arm would likely be most prone to injury, while externally loaded pushing on the pushrim and at extremes of range and the trunk range of motion has been shown to be as high as 15° (Boninger et al. 1998). During maximum acceleration the forces caused by inertia of the limb are the largest, and a large ROM during the entire stroke may be correlated associated with injuries to the upper extremity (Boninger et al. 1998). Stable parameters characterize the propulsive stroke and differ with speed, and these parameters may provide insight into the causes that generate mechanical injuries in manual wheelchair and are useful to reduce the risk of injury of the shoulder and elbow (Boninger et al. 1998).

37.6 Ascending a Curb and Overcoming Irregular Pathways

The U/E mechanical and muscular demands significantly increased as the curb's height progressed and, especially at the shoulder and elbow joints, were found to progressively augment as well as the risk of developing secondary musculoskeletal U/E impairments as the height of the curb increased in manual wheelchair users with SCI (Lalumiere et al. 2013). In fact, when progressing from a 4 to 12 cm curb, net joint peak moments at the shoulder increased in flexion and internal rotation by about 2.2 times, in adduction by about 2.8 times, and in elbow flexion by about 1.8 times (Lalumiere et al. 2013). A similar tendency was also observed for the MURs of the main muscles studied while progressing from the 4 to the 12 cm curb, showing an increase of about 2.7 times for the anterior fibers of the deltoid, 1.7 times for the biceps brachii, 2.8 times for the triceps brachii, and 6.1 times for the clavicular fibers of the pectoralis major (Lalumiere et al. 2013). Despite the fact that the elbow predominantly

extends when ascending the curb, elbow flexion efforts are generated during this phase contrary to popular belief frequently expressed by rehabilitation professionals that pay attention especially on elbow extensors (Lalumiere et al. 2013). Ascending a curb requires that the resultant reaction force vector applied at the handrim be posteriorly oriented to the elbow joint axis of rotation in the sagittal plane of motion while the length of the lever arm (perpendicular distance from this vector to elbow joint axis of rotation) influences the magnitude of the net elbow flexion moment computed when ascending curbs (Gagnon et al. 2009b). Forward trunk flexion combined with shoulder flexion and elbow extension augments significantly as the height of the curb increases but may enable individuals with SCI to strategically orient the resultant reaction force posterior to the elbow joint axis of rotation as U/E loading rises during wheelchair curb ascent (Lalumiere et al. 2013). Such a strategy may also accommodate the long head of the biceps brachii, a bi-articular muscle that contributes to the substantial shoulder flexion moment that is simultaneously generated (Lalumiere et al. 2013). The relative muscular demand of the long head of the triceps during this period, even if of lesser intensity than the long head of the biceps brachii, suggests that co-contraction occurs between the elbow flexor and extensor muscle groups (Lalumiere et al. 2013). A similar elbow situation has been described during manual wheelchair propulsion (Van der Woude et al. 2001) and sitting pivot transfers (Gagnon et al. 2009a). The substantial U/E demands while ascending 12 cm curb, especially those straining the shoulder joint, are greater than the ones documented at the shoulder during other wheelchair-related activities such as wheelchair level propulsion (Kulig et al. 2001; van Drongelen et al. 2005) and weight-relief lifts (Gagnon et al. 2008). The forward trunk flexion, which has been found to progress as the height of the curb increases, starts early in the caster pop phase and continues to increase during the first part of the curb ascent phase and may facilitate the ascent of the curb, especially as the height of the curb increases (Lalumiere et al. 2013). The forward trunk flexion may increase the intensity of the forward momentum given the prominent mass of the head and trunk segments and may help to optimize the orientation of the force applied at the handrim, probably due to a greater vertically directed force than level propulsion, to facilitate wheelchair curb ascent (Lalumiere et al. 2013). This trunk optimization strategy, when initiated with proper timing, may reduce U/E efforts when ascending a curb especially when the height is equal or less than 8 cm (Lalumiere et al. 2013). Consequently a specific and structured training method for wheelchair curb ascent is very important, particularly during the initial intensive rehabilitation phase following a SCI, where the patients can appreciate various forward trunk flexion movement strategies and the effects on magnitude, velocity, and timing just prior and during curb ascent since it may have positive effects on motor performance and skill acquisition (Lalumiere et al. 2013). Ascending a curb requires upper limb efforts that potentially expose the U/Es, especially the shoulders flexors and internal rotator as well as for the elbow flexors, to an increased risk of developing secondary musculoskeletal diseases (Lalumiere et al. 2013). It is essential for manual wheelchair users with SCI to rapidly learn the optimal position of the hands on the handrims, to get experience and skill training, to combine body and wheelchair weight and wheelchair configuration (rear axle position, seat tilt, backrest inclination), to best modulate intensity and timing of their forward trunk flexion, to generate additional mechanical energy to successfully ascend a curb, and to continue advocating for accessible physical environments (Lalumiere et al. 2013). Physiotherapists and trainers should optimize the absolute strength-generating capability of the shoulder flexor and adductor muscles along with the elbow flexor muscles, minimize muscular fatigue, involve other muscle groups, and reduce the relative demand at the U/Es and the risk of U/E secondary impairments in an effort to preserve muscle balance at these joints during curb ascent especially when the curb is 8 cm or higher (Lalumiere et al. 2013). If anterior wheels have a reduced diameter, it will be easier to guide the wheelchair and make faster changes of directions, but on the other hand, it will be more difficult to drive on irregular pathway (dips, sewer covers, gravel, and other different kinds of roughness). To overcome these irregular pathways, patients with SCI should learn to perform a wheelie wheelchair propulsion even for significant distances (keeping the equilibrium of the body and of the wheelchair with anterior wheels lifted from the pathway) to avoid any contact between the anterior wheels and the pathway to reduce excess mechanical load on upper limbs and to prevent wheelchair capsizing. During wheelie wheelchair propulsion, there is high activity of the extensor carpi radialis brevis and longus and of the biceps brachii, the elbow is flexed at about 90°, and the shoulder is flexed at 20°, and this configuration may predispose to develop epicondylitis, distal biceps brachii tendinopathy, and shoulder impingement.

Patients with SCI should learn to perform a wheelie wheelchair propulsion as well as to ascend or descend a curb to avoid the contact between anterior wheels and the curb and the excess mechanical load on upper limbs that the contact would generate (Fig. 37.7).



Fig. 37.7 Ascending a curb and wheelie wheelchair propulsion (**a** ascending a curb; **b** descending a curb; **c** wheelie wheelchair propulsion)

37.7 Elbow Overuse Prevention

Since persons with SCI depend on their arms for mobility and activities of daily living, shoulder pain, when present, will affect their independence, their participation in the community, and their quality of life; for this reason there is a need to study alternative manners of wheelchair propulsion, where shoulder load, and consequently the risk for injuries of the upper extremity, is lower (Ursina et al. 2012). The handbike is one of the alternative ways of propulsion that is increasingly used for regular exercise, which is a good alternative to handrim wheelchair propulsion since it is more efficient and physiologically less straining (Ursina et al. 2012). Studies regarding wheelchair propulsion have shown that the shoulder load is lower during handcycling and the joint loading (glenohumeral contact force) is significantly lower for handcycling than for wheelchair propulsion at all power output levels. The glenohumeral contact forces during handcycling are distributed over the propulsion cycle with the highest forces measured around the end of the cycle and at the least straining condition of 25 W, which represents an everyday condition for wheelchair propulsion; the

mean glenohumeral contact force was 268 N for handcycling, whereas for wheelchair propulsion a mean glenohumeral contact force of 347 N (+29%) was measured (Ursina et al. 2012). During wheelchair propulsion at the most physical effort (55 W), the mean value of the glenohumeral contact force during handcycling was 345 N and a mean glenohumeral contact force of 585 N was measured, which is 70% higher than during handcycling (Ursina et al. 2012). The differences of the peak values were even more pronounced, with 773 N during handcycling and 1510 N during wheelchair propulsion, and muscle forces were lower during handcycling for the majority of the shoulder muscles (Ursina et al. 2012). The exceptions were the clavicular part of the deltoid and the teres major, which produced more relative muscle force during handcycling (Ursina et al. 2012). The highest difference in muscle force between the two propulsion devices was found in the supraspinatus, the infraspinatus, and the biceps; the peak values of the biceps and supraspinatus muscle, respectively, were 2.3 times and 3.3 times higher during wheelchair propulsion at 55 W compared with handcycling, and in handcycling, the muscles produce force over the whole propulsion cycle and are recruited in a balanced manner (Ursina et al. 2012). Infraspinatus and supraspinatus, which are most prone to overuse injuries in wheelchair-dependent persons, were less stressed during handcycling versus wheelchair propulsion since higher muscle forces are produced during the push phase, as well as at the start and the end of the recovery phase, and at the beginning of the recovery phase during handcycling, the most active muscles were the scapular part of the deltoid and the serratus anterior (Ursina et al. 2012). Handbike represents a good alternative propulsion mode for outdoor mobility and exercise that might reduce the development of impingement, rotator cuff, and elbow-related problems (Ursina et al. 2012).

Another alternative modes of wheelchair propulsion are the use of a mobility assistance dog (ADMob). The ADMob, compared to doing the same task without assistance in a MWU with SCI, reduces U/L efforts like handrim forces, net joint movements, and relative muscular utilization and improves efficiency during uphill propulsion, ramp ascent, and other wheelchair-related tasks requiring good skills like opening doors, carrying bags, and picking up objects from the floor (Gagnon et al. 2013). This is the reason why rehabilitation professionals occasionally recommend the use of an assistance dog for mobility (ADMob) to facilitate manual wheelchair propulsion and to improve manual wheelchair skills (Gagnon et al. 2013). During uphill propulsion with the ADMob, the total and tangential forces applied at the nondominant handrim, along with the rate of rise of force, are reduced, while mechanical efficiency improved compared to uphill propulsion without the ADMob, and the ADMob facilitates independent performance of this complex task, limits the development of fatigue, or reduces U/L risk exposure (Gagnon et al. 2013). Similarly, the resultant net joint movements (wrist, elbow, and shoulder) and the relative muscular demands (biceps, triceps, anterior deltoid, pectoralis major) decreased during uphill propulsion with an ADMob versus without an ADMob (Gagnon et al. 2013). To avoid potential adverse effects like reduced physical fitness and reduced U/L, scapulohumeral, scapulothoracic, and trunk muscle strength associated with the long-term use of an ADMob, it is necessary to perform a specific training and reinforce program of the trunk and of the upper limb (Gagnon et al. 2013). Optimizing physical capacity, physical condition, and muscle strength through regular exercise is important for persons with spinal cord injury (SCI) and helps with the efforts of activities of daily living, to prevent long-term health problems such as diabetes or cardiovascular disease (Ursina et al. 2012). During wheelchair propulsion on a slope, it is necessary to adopt and alternate two different techniques; the zigzag trajectory will decrease the degree of the slope, reducing the mechanical load on upper limbs, while the wheelie wheelchair propulsion will brake and slow down the propulsion on the slope and will reduce the mechanical load on upper limbs. It is important to use gloves to protect hands, in particular during wheelchair propulsion on a slope, to avoid that the increases of the temperature of the handrim, due to the high frictional forces generated during hand brake, could damage the hands.

37.8 Wheelchair Athletes

Participation in organized sports is markedly increased (Fagher and Lexell 2014) since it is a natural way for people with disabilities to be physically active to improve and maintain cardiovascular fitness, self-efficacy, and self-perceived quality of life (Blauwet and Willick 2012). However, participation in sports also increases the risk of sports-related injuries, either acute trauma or overuse injury (Fagher and Lexell 2014). Wheelchair sports, such as basketball, rugby, tennis, and racing 100 m through to the marathon, are becoming increasingly popular for many athletes with disabilities. A potential issue for many wheelchair athletes is how to maximize the training-related gains in performance while minimizing the risk of injuries (Churton and Keogh 2013). Upper limb injuries, particularly to the shoulder, appear common in wheelchair athletes due to repetitive use of the upper extremities for propulsion and to the accumulation of stress placed on this joint during activities of daily living, training, and competition (Fagher and Lexell 2014; Churton and Keogh 2013; Slocum et al. 2015). Sport performance in wheelchair sports is dependent on athlete conditioning and skill, wheelchair configuration, and the wheelchair-athlete interface. Scientific publications suggest that rearwheel camber, wheel

size, handrim, and configurations and seat positioning influence the ergonomics of sport performance for athletes who compete using sports wheelchairs (Slocum et al. 2015). Patatoukas et al. (2011) showed that wheelchair basketball was the sport with the highest percentage of injury (30.9) among a group of Greek elite athletes. Chung et al. (2012) demonstrated in a prospective study that wheelchair foil fencers had a higher overall IR (3.9/1000 h) compared with able-bodied fencers (2.4/1000 h). Furthermore, wheelchair athletes without active trunk control were more susceptible to injury (4.9/1000 h) compared with athletes with good trunk control (3.0/1000 h) (Fagher and Lexell 2014). The most prevalent injuries in the wheelchair athletes were upper extremity injuries (73.8%), whereas the able-bodied fencers had a higher percentage of lower extremity injuries (Fagher and Lexell 2014). The mechanisms of injury are often a result of repeated microtrauma to the soft tissue structures, with no single identifiable incident responsible for injury (Fuller et al. 2006). Athletes who reported most injuries were those involved in repetitive wheelchair pushing, during competition, and it seems that athletes participating in ball sports like wheelchair rugby, football 7-a-side, seated volleyball, and football 5-a-side are more prone to acute injuries (Willick et al. 2013). During the Winter Paralympic Games 2002, Vancouver, 77% of all injuries were acute injuries (Webborn et al. 2006). Ferrara et al. (2000) demonstrated that 65% of the injuries were acute in a population of elite wheelchair athletes, and 32% of the injuries were classified as major since 22 days or more were missing from competitions. Wheelchairs are available in several sizes and are made to move in any direction, and the basic castor consists of a wheel, an axle, a fork, and a stem. Adjustments (seatback angle and seatback height) and material properties of the seat and backrest have to be moisture proof, abrasion resistant, and easily cleaned, and a smaller wheel has greater probability to damage than a larger wheel, and the rolling resistance is inversely proportional to the diameter of the wheel (Dellabiancia et al. 2013). Racing wheelchairs are designed and customized to the functional abilities and anatomy of each user in order to maximize speed and efficiency (Slocum et al. 2015). Large wheels, small handrim diameters, and racing gloves afford wheelchair racers propulsion dynamics that are the most efficient for sprinting and continuous propulsion among wheelchair sports (Slocum et al. 2015). A three-wheeled design and lightweight components such as high-pressure, tubular tires, precision hubs, carbon-fiber wheels and spokes, small handrims, and compensator steering further optimize efficiency (Slocum et al. 2015). Athletes who compete using sports wheelchairs may also participate in a wide variety of team sports, including the so-called wheelchair court sports (basketball, tennis, and rugby) (Slocum et al. 2015). Rearwheel camber is typically more extreme for the wheelchair court sports and lends itself to improved maneuverability on court but negatively affects sprinting performance (Slocum et al. 2015). Rearwheel camber provides improved lateral stability to wheelchair racers and enhances the chair's responsiveness, while aerodynamic positioning of the athlete's body in a racing chair with a flexed trunk position reduces frontal surface area and further improves efficiency and speed (Slocum et al. 2015). Physiologic demands during competition may also differ depending on the athletes' seating position, player role, and sport-specific demands for game play (Slocum et al. 2015). For instance, wheelchairs used in the sport of wheelchair rugby must not exceed a maximum wheel diameter of 70 cm or a maximum seat height of 53 cm, while in the sport of wheelchair basketball maximum seat heights vary by players' sport classification rating (Slocum et al. 2015). A typical sitting position for these athletes involves posterior pelvic tilt, increased thoracic kyphosis, and forward head position, especially for athletes with SCI (Slocum et al. 2015). This position results in anterior displacement of the shoulder girdle; in this way tonic contraction of the rotator cuff muscles may become the primary means of preventing inferior translation of the humerus (Slocum et al. 2015). Lowering the seat, and therefore decreasing the vertical distance between the axle and the shoulder, makes more of the handrim available for the push cycle, increasing the push angle and contact time between hand and rim (Churton and Keogh 2013). Kotajarvi et al. (2004) found that average peak radial and axial force components were also significantly higher in lower seat positions. This may be advantageous as it implies that more force is being directed perpendicular to and toward the axle, respectively, in the lowest seat height positions that were tested (Churton and Keogh 2013). A low seat angle achieved by increasing the wheel camber may also provide advantages for low point players in wheelchair basketball and rugby (Churton and Keogh 2013). Increasing the camber of the wheels will broaden the wheelchair's base of support and improve stability in contact situations; however, increasing wheel camber have some disadvantages, and Faupin et al. (2004) found that increased rearwheel camber increases residual torque and total muscular power required during the push phase for a given wheelchair velocity and a significant decrease in the mean wheelchair velocity per arm cycle. New wheelchair sport designs and chair setup are being developed in many ways to improve propulsion biomechanics in ways that both may be beneficial for sport performance and reduce injury risk, and some aspects such as acceleration, maximal speed, and turning capacity can be modified to prevent tipping over so to fit specific sport needs (Churton and Keogh 2013). A comparative study by Coutts (1990) involving wheelchair basketball players and wheelchair racers found that the basketball wheelchairs had larger diameter handrims, and Coutts suggested that the greater handrim diameters of the wheelchair basketball players allowed them greater time to apply propulsive forces (impulses) and hence develop greater levels of acceleration as required due to the

stop-start and change of direction nature of wheelchair basketball. A larger handrim may also have some negative consequences since larger handrims may require athletes to apply propulsive torques over larger range of motions (Churton and Keogh 2013).

Other activities required for game play in the wheelchair court sports such as player pursuit, wheelchair maneuvering, overhead activities, and ball handling may also predispose athletes to accumulated microtrauma and injuries of the shoulders, wrists, neck, and lower back (Churton and Keogh 2013; Slocum et al. 2015). Dynamic anatomic factors such as scapulothoracic dyskinesis, limited dynamic postural control of the lumbar spine and pelvis, axial weight-bearing forces, and poor shoulder flexibility may all contribute to subacromial impingement syndrome in wheelchair athletes (Slocum et al. 2015). In a study of wheelchair basketball players, researchers demonstrated significantly increased shoulder pain symptoms in athletes with less trunk control (Slocum et al. 2015). As with able-bodied athletes, training factors such as overuse, lack of appropriate warm-up activities, repetitive positioning, and fatigue may also increase athletes' risk of injury (Slocum et al. 2015). The two most common peripheral nerve entrapment syndromes in wheelchair athletes are carpal tunnel syndrome affecting the median nerve and ulnar nerve entrapment at the wrist or the elbow, both likely due to repetitive trauma and pressure over soft tissue structures during manual wheelchair propulsion, and optimization of non-operative management through activity modification, bracing, and injections which is important prior to considering surgical intervention (Slocum et al. 2015). Wheelchair biomechanics have been found to predict median nerve function in manual wheelchair users, with greater pushrim forces more likely to be associated with median nerve injury (Slocum et al. 2015). Since posterior shoulder muscle weakening and anterior shoulder muscle shortening are suggested as the sole reasons for such issue (Curtis et al. 1999), exercise methods, such as rowing, backward propulsion, exclusive retraction of the shoulder (Olenik et al. 1995), strengthening programs for rotator cuff musculature, and scapular stabilizers (especially the serratus, rhomboideus, and lower trapezius muscles), as well as proprioceptive techniques and flexibility exercises, are needed for prevention, conditioning, and rehabilitative treatment methods of shoulder injuries in athletes competing in wheelchair sports (Slocum et al. 2015; Moon et al. 2013).

37.9 Wheelchair Athletes and Basket

Wheelchair basketball is the most popular exercise activity among individuals with spinal cord injury (SCI). Wheelchair basketball includes upper limb propulsion, starting, stopping, and direction changes of the wheelchair as well as shooting, passing, dribbling, and rebounding (Wang et al. 2005). These activities and repetitive action of the arms require a balance between upper body muscular strength and endurance (Uzun et al. 2012). Fatigue presents an important limiting factor during sport performance, and surface electromyography (SEMG) has great potential for assessing muscle fatigue dynamics, endurance, and maximal torque values objectively and noninvasively in wheelchair basketball athletes with SCI (Uzun et al. 2012). Wang et al. (2005) described that elbow flexion had significant contributions to the average rebound in wheelchair basketball. Dubowsky et al. (2009) found that biceps brachii (BB) (in the initial stage of propulsion) and triceps brachii burst duration throughout propulsion is larger in paraplegic (Uzun et al. 2012). In this study they found that the endurance properties of the elbow flexors of wheelchair basketball player (WBP) were better than sedentary individuals, but similar to basket player (BP) (Uzun et al. 2012). Considering the additional demands of wheelchair basketball player on the upper extremities (as compared to regular basketball), it is likely that WBP will benefit from improved upper extremity endurance and strength training (Uzun et al. 2012). In another study the authors found that in wheelchair basketball players, delayed-onset muscle soreness (DOMS) emerges a couple of hours after an eccentric activity, especially in individuals who are not used to this kind of exercise, and causes a temporary decrease in shooting performance, activity, joint movement, angle and muscle power, increased muscle pain of the elbow flexors (measured by using a visual analogue scale (VAS) and determined by palpating the distal portion), temporary increase in the blood creatine kinase (CK), and joint positioning sense loss (it appears in the 30th min after exercise and through 24 and 48 h after the exercise) (Serinken et al. 2013). Saxton et al. (1995) recorded significant positioning sense loss immediately after the load on the elbow joint flexion muscles, and Walsh et al. (2004) concluded that there is a significant positioning sense loss when the subjects are asked to match positioning of the forearm muscles after an eccentric exercise protocol. The muscle pain which occurs immediately after the eccentric exercise is confirmed by the study of Micklewright (2009) and Friden et al. (2001) has reported that the increase in the muscle pain level could decrease the muscle power and the shooting percentage. The periodization of the eccentric exercises must keep in consideration the long recovery period required before the match and that the time required for the DOMS effects to disappear is around 48 h (Serinken et al. 2013).

37.10 Wheelchair Athletes and Tennis

Since these athletes may often require the use of the injured body part for activities of daily living outside of competition, there are difficulties to guarantee the necessary relative rest of the upper limb to obtain the best treatment (Slocum et al.

2015). For example, wheelchair tennis players should perform a flexor strengthening program in nondominant shoulder joint, an extensor strengthening program in elbow joint, and flexor strengthening program in nondominant elbow joint since this study by Moon et al. (2013) showed that:

- At an angular velocity of 60°/s, shoulder joints showed higher ES (extension strength) compared to FS (flexion strength) in both arms ($P < 0.001$), and elbow joints showed higher FS compared to ES ($P < 0.001$).
- Both shoulder and elbow joints showed significantly higher score of dominant-side muscle strength compared to nondominant-side muscle strength ($P < 0.01$).
- At an angular velocity of 180°/s, shoulder joints showed higher ES score compared to FS in both arms.
- Elbow joints showed higher FS compared to ES and showed a tendency similar to the measured results that came from the condition of angular velocity of 60°/s.
- Extension strength (ES) was significantly higher than flexion strength (FS) ($P < 0.001$).
- Ipsilateral (IR) in both sides and bilateral (BR) in ES were maintained within normal range, whereas BR in FS was lower than normal range in shoulder joint (ipsilateral (IR) and bilateral (BR) balance ratios were calculated with isokinetic strength at 60°/s).
- Elbow joint FS was significantly higher than ES ($P < 0.05$).
- IR and BR were lower than normal range.

Consequently, the different tendency in IR between shoulder and elbow joints and lower IR and BR in elbow joints could be the characteristics in male wheelchair tennis players (Moon et al. 2013). In another study the authors confirmed the importance of a sport-specific training in wheelchair athletes, and they demonstrated significant improvements in strength and power parameters as a result of resistance training (maximal velocity measured from a bench press throw improved from 2.39 to 2.49 m/s, maximum bench press acceleration increased by 24.6%, maximum force increased by 31.6%, and maximum rate of force development demonstrated an enhancement of 71.5%) with effects of training that were comparable to control subjects without spinal cord injury (Churton and Keogh 2013).

37.11 Paralympic Athletes

Paralympic sports have seen an exponential increase in participation since 16 patients took part in the first Stoke Mandeville Games on the opening day of the 1948 London Olympic Games (Webborn and Emery 2014). In 1960, the International Stoke Mandeville Games were held in Rome, and since that time, the Games have been held in the country selected for the Olympic Games. More than 4000 athletes took part in the London 2012 Paralympic Games (Webborn and Emery 2014), and the injury survey captured data from 3565 athletes (84% compliance by athletes) from 160 delegations (98% compliance by delegation) during training and competition in the 20 summer sports (Willick et al. 2013). At the London 2012 Summer Paralympic Games, a total of 49,910 athlete-days were monitored, 633 injuries in 539 athletes were documented, the incidence of injuries was relatively low at 12.7/1000 athlete-days, injury rates were similar in male and female athletes, the lowest rate was in the younger athletes, and 51.5% of injuries were acute traumatic injuries (Willick et al. 2013). The injury panoramas today are similar in athletes with disabilities compared with able-bodied athletes; in fact, the injury incidence proportion during the Summer Paralympics Games 2012 was 17.8 injuries/100 athletes (Willick et al. 2013) compared with the injury rate of 12.9 injuries/100 athletes during the Summer Olympic Games (Engebretsen et al. 2013). Higher injury rates were found in older athletes and certain sports such as football 5-a-side (22.4 injuries/1000 athlete-days) followed by powerlifting, goalball, wheelchair fencing, wheelchair rugby, athletics, and judo (Willick et al. 2013). The lowest IRs were found in sports like sailing (IR 4.1 injuries/1000 athlete-days), rowing (IR 3.9 injuries/1000 athlete-days), and shooting (IR 2.2 injuries/1000 athlete-days) (Willick et al. 2013). Upper limb injuries was predominant and represents the 50.2% of all injuries; the 17.7% of all injuries involved the shoulder, in the 11.4% the wrist/hand, in the 8.8% the elbow, and in the 7.9% the knee that is the most common injured region of the lower limb (Willick et al. 2013). Clarsen et al. (2013) showed that overuse injuries represented 49% of all health problems (acute injuries 13%) in 116 Norwegian Olympic and 26 Paralympic athletes preparing for the 2012 Summer Olympic/Paralympic Games. During the Winter Paralympic Games 2010, 57.5% of the injuries were overuse injuries (Webborn et al. 2012). There is a risk that the demands of sports activities together with daily wheelchair pushing result in insufficient time for rest and recovery of the musculature in wheelchair athletes (Curtis and Black 1999; Ferrara et al. 2000). The concept of functional movement variability is a dynamical systems theory principle that may be relevant to coaches, sports science, and medicine staff who work with Paralympic athletes (Churton and Keogh 2013). Functional variability represents the ability to adopt a flexible (variant) movement control strategy that enables the athlete to perform at a consistently high level even when the interaction of the three levels of constraints has changed (Churton and Keogh 2013). It means that the minimization of all movement variability (absolute invariance of technique) may be suboptimal and can lead to increased injury risk as the same anatomical structures would have to produce and/or tolerate the muscular and external

forces, respectively, and this situation can explain the reason why the wheelchair athletes have higher rates of shoulder, elbow-arm, and forearm-wrist injuries compared to other Paralympian athletes (Churton and Keogh 2013). On the other hand, it is difficult to determine how the interaction of the intrinsic (organism) and extrinsic (task and environmental) constraints of wheelchair propulsion may have influenced these injury rates (Churton and Keogh 2013). Wheelchair athletes that participate in sports like basketball, rugby, and tennis encounter a range of task and environmental constraints that are different from track athletes, as they must frequently accelerate and decelerate, frequently start and stop, regularly propel on outdoor and inclined surfaces, change direction at speed, and perform sport-specific skills to adjust to the task constraints during the game, and all these situations that generate peak shoulder forces and moments (there is a larger end of ranges of motion of the propulsion phase) represent risk factors for upper limb injuries for an increased and cumulative loading on the upper limb (Churton and Keogh 2013).

Wheelchair propulsion between wheelchair racing and court sports may differ; for wheelchair racing, where the specific movement dynamics may involve starting, accelerating, steady-state wheeling, and deceleration phases, it is important to obtain and sustain a greater velocity than the opponents and to obtain maximum speed, and the athletes must apply an increasingly large propulsive force to the handrim, reduce the period of time available to achieve a high impulse and as speed increases, and adapt their stroking patterns during wheelchair propulsion to the variations of the extrinsic conditions (task and environmental) (Churton and Keogh 2013). O' Connor et al. (1998) found that a longer hand contact time period and a slower wrist velocity would create a decelerating force and lead to a loss of wheelchair velocity at higher speeds (Churton and Keogh 2013). In wheelchair ball sports like basketball, rugby, and tennis, the specific movement dynamics involve braking, change of direction, striking, catching, physical contact with opponents, and/or blocking (Churton and Keogh 2013). Goosey-Tolfrey et al. (2005) found that tennis players had significantly reduced acceleration and maximum velocities during the first three pushes while holding a racquet in contrast to trials done without a racquet since holding the racquet interfered with the hand contact on the rim, so there is the need for wheelchair tennis players to use different ways to hold their tennis racquet while accelerating that allow more efficient transfer of muscular forces to the handrim (Churton and Keogh 2013). Coutts (1990) showed that, compared to track athletes, basketball players had a significantly faster wheelchair velocity during the first push (achieving 80% of their peak speed during the third push) and similar speeds during the second and third pushes but that track athletes attained a higher peak speed during a 10 s effort. The effect of different task constraint types of sport (racing versus court) and the indirect effect of speed have a number of implications, so to minimize injury risk in different competitive conditions and tasks, Paralympic athletes need to train utilizing some variations of the levels of constraint that they will encounter in competition (Churton and Keogh 2013). For example, wheelchair rugby players need to train not only performing straight line but also changes of direction sprinting; otherwise their training will not match the sport-specific skills and the time-motion characteristics of the sport, running the risk to reduce the performance and to increase the injury risk (Churton and Keogh 2013). The interaction of organism constraints such as players' disability, classification level, chair setup, stroke patterns, and characteristics (semicircular, single looping, double looping, and arcing) are important factors to consider when developing the individualized and sport-specific training program required by a wheelchair athlete to prevent and reduce the risk of injury and to perform at their best conditions (Churton and Keogh 2013).

Conclusions

Upper limb injuries appear common in patients with spinal cord injury (SCI) and in wheelchair athletes since they need to perform frequent weight-relief lifts and sitting pivot transfers and to use manual wheelchair propulsion as their primary method of mobility, during activities of daily living, training, and competition in sports. It is necessary during the initial intensive rehabilitation process among individuals with SCI to develop task-specific strength training protocols to reach optimal shoulder strength before initiating transfer training and weight-relief lifts. The use of human assistance or a technical aid like a sliding board when individuals with SCI are performing sitting pivot transfers should be encouraged until these individuals reach sufficient strength-generating capability to potentially minimize UL mechanical loads. A proper use of different transfer skills, transfer techniques, and propulsion patterns that reduce upper limb joint forces and moments may minimize the risks associated with secondary injuries and prevent injuries to upper limbs.

Optimizing physical capacity, physical condition, and muscle strength through regular exercise is important for persons with spinal cord injury (SCI) and helps with the efforts of activities of daily living, to prevent long-term health problems such as diabetes or cardiovascular disease.

The interaction of organism constraints such as players' disability, classification level, chair setup, stroke patterns, and characteristics are important factors to consider when developing an individualized and sport-specific training program required by a wheelchair athlete to prevent and reduce the risk of injury and to perform at their best conditions.

Key Points

- Weight-relief lifts (WRL) should be performed routinely by individuals with SCI, every 15–30 min of sitting and supporting body weight off the seat for at least 30 s for a period of about 2 min to bring the tissue oxygen level back to an unloaded level
- Elbow pain affects about 1 out of 4–6 patients, so it is important to understand causes of pain and to use preventive measures to reduce pain and functional limitation
- Individuals with SCI have to be educated and should learn how to perform correct transfer techniques and to use transfer skills during rehabilitation to prevent wheelchair users to develop upper limb pain and overuse-related injuries, such as rotator cuff tears, elbow pain, and carpal tunnel syndrome
- During sitting pivot transfers, wheelchair users should angle their wheelchairs appropriately relative to the target surface (20–45° degrees) to reduce the large internal rotation shoulder moments on the leading side which can occur when using a proper leading handgrip
- Physiotherapists and trainers should optimize the absolute strength-generating capability of the shoulder flexor and adductor muscles along with the elbow flexor muscles, minimize muscular fatigue, involve other muscle groups, reduce the risk of U/E secondary impairments, and preserve muscle balance at these joints during curb ascent especially when the curb is 8 cm or higher
- When a wheelchair patient is ascending a curb, co-contraction occurs between the elbow flexor and extensor muscle groups
- To overcome irregular pathways, patients with SCI should learn to perform a wheelie wheelchair propulsion even for significant distances to avoid any contact between the anterior wheels and the pathway to reduce excess mechanical load on upper limbs and to prevent wheelchair capsizing
- In wheelchair basketball players, the periodization of eccentric exercises must keep in consideration the long recovery period required before the match and that the time required for the DOMS effects to disappear is around 48 h
- Wheelchair tennis players should perform a flexor strengthening program in nondominant shoulder joint, an extensor strengthening program in elbow joint, and flexor strengthening program in nondominant elbow joint
- Wheelchair players need to train the sport-specific gesture, skills, and the time-motion characteristics of the sport to increase the performance and to reduce the injury risk

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Assessment Tools and Orthoses for the Athlete's Return to Competitions

38

Gabriele Fiumana, Elisa Tongiani, and Giuseppe Porcellini

38.1 Introduction

Return to competitions is the most ambitious goal pursued by orthopedic surgeons and rehabilitation therapists who have managed an athlete's overload or musculoskeletal injury. The upper limb movement involved in overhead sports is characterized by high velocity, acceleration, and long lever arms, which have the potential to induce significant capsuloligamentous injury. The shoulder needs to be highly mobile in all planes without being unstable, while the elbow must resist varus and valgus stress and at the same time maintain an effective flexion-extension and pronation-supination.

Once the condition involving the injured compartment has successfully been treated, it is essential to establish whether the adjacent limb and thoracic joints present altered muscle strength or motor patterns. Pain, immobility, and hypermobility generate compensatory postures that in turn can give rise to further medium- and long-term problems. Often such changes are not visible in everyday movements but are easier to detect in athletic gestures. For instance, the assessment of a baseball pitcher treated for ulnar collateral ligament (UCL) injury should not merely involve an evaluation of valgus stress stability with passive tests (e.g., milking test) but also scapulothoracic and scapulohumeral kinematics in an appropriate context (e.g., the pitching motion). Moreover, the athlete's career requirements often make it difficult to address a problem in the short term; it is thus essential to provide means and tools to reduce symptoms and avoid worsening of the clinical picture.

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38.2 Strength Assessment

Strength assessment has several uses in rehabilitation, especially in progress monitoring and quantification of residual strength.

Manual muscle assessment is a first-key approach to strength evaluation, but quantitative assessment of global strength, which best reflects hand and forearm function, is also needed (MacDermid 2005). Several different tools are available to measure the strength of a musculoskeletal segment; they include dynamometers providing analytical, isokinetic, or functional assessment.

Dynamometers providing analytical evaluation, such as the Newman and the Hammersmith myometer, are not sufficiently reliable, due to limitations that involve, respectively, device placement with respect to the joint fulcrum (accuracy) and operator dependence (repeatability).

Isokinetic dynamometers have been in use for some decades. Some appear to afford accurate assessment of hand functional gestures related to activities of daily living (ADL) and work tasks. Dynamometers using robotic actuators are currently the most advanced means to measure muscle strength but entail three significant limitations: steep cost, poor ease of use, and scant available data regarding the analytical isokinetic evaluation of small muscle compartments, with the exception of global strength testing for the hand and fingers.

The most reliable functional dynamometer in terms of accuracy and repeatability of handgrip strength measurement is the Jamar® (Fess 1992; Bechtol 1954; Mathiowetz et al. 1984; Bohannon 1986; España-Romero et al. 2010) isometric dynamometer (Preston Corp, Jackson, MI, USA), which records values of up to 90 kg (200 lb) with 2 kg increments (Fig. 38.1). The handgrip strength is very important for the elbow evaluation and to indirectly control the functionality of the elbow.

Its adjustable handle, allowing for five grip positions to accommodate different hand sizes (Fig. 38.2), provides for more effective recruitment of intrinsic and extrinsic muscles.

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Fig. 38.1 Jamar isometric dynamometer

In fact the first three positions test the overall work of intrinsic and extrinsic flexors, whereas the last two positions test extrinsic flexors.

There is no consensus on the patient position that maximizes handgrip strength test reliability. According to Mathiowetz and coworkers (Mathiowetz et al. 1985a), higher strength values are obtained with the elbow in 90° of flexion, whereas Savva and colleagues and Kuzala and colleagues believe that it should be fully extended (Kuzala and Vargo 1992; Savva et al. 2010). According to Pryce (1980), handgrip strength decreases significantly with the wrist beyond 30° of ulnar deviation and 15° of flexion compared with the neutral wrist position. In contrast, a study by Taraoka (1979), who tested handgrip strength with the extended elbow in a number of body positions, found a progressive decrease as subjects passed from standing to seated and finally supine position.

38.2.1 Handgrip Strength Test Administration

To obtain an accurate measurement, the subject is asked to sit on a chair about 45 cm high in a comfortable position, leaning against the back of the chair with the trunk in neutral position, the feet apart, the shoulders adducted and aligned in the frontal plane, the elbow flexed to 90°, the forearm in neutral position, and the wrist in slight extension (0–20°) and slight ulnar deviation (Fess 1992; Mathiowetz et al. 1985b; Woody and Mathiowetz 1988) (0–15°) (Fig. 38.3).

The weight of the dynamometer is supported by the operator, to avoid any strength dispersion. The patient is first



Fig. 38.2 Different grip positions



Fig. 38.3 Patient positioning

asked to perform two submaximal tests, to enable the operator to check for and correct any compensatory movements. The actual test involves a 5 s maximal contraction grip that is repeated three times with 10 s rest intervals. The dominant side is tested first. The value of each contraction is reported in kg in the patient's card (Table 38.1), and the average value of the three tests performed with each limb is calculated (Stegink Jansen et al. 2003). Values are then compared to reference values that account for the job task performed and age. Even though some researchers have suggested comparing the strength values of the right hand and left hand, strength differences of up to 40% have been described between the limbs, and the use of reference tables seems preferable (Tables 38.2 and 38.3).

Notes Verbal instructions for the patient:

"This test measures the grip strength of your hand. You'll need to hold the dynamometer in the right (left)

Table 38.1 Jamar® dynamometer Hand grip

FONDAZIONE SALVATORE MAUGERI
CLINICA DEL LAVORO E DELLA RIABILITAZIONE I.R.C.C.S.

ISTITUTO SCIENTIFICO DI VERUNO

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Taken Handheld		Test 1	Test 2	Test 3	Average
Basal Date:.....	Right Hand				
	Left Hand				
Control Date:.....	Right Hand				
	Left Hand				
Control Date:.....	Right Hand				
	Left Hand				
Control Date:.....	Right Hand				
	Left Hand				
Control Date:.....	Right Hand				
	Left Hand				

Table 38.2 Reference strength values based on work

Hand grip	Men		Women	
	Dominant hand	Non-dominant hand	Dominant hand	Non-dominant hand
Skilled worker	47.0	45.4	26.8	24.4
Sedentary subject	47.2	44.1	23.1	21,1
Manual activities	48.5	44.6	24.2	22.0

Table 38.3 Reference strength values based on age

Age (years)	Men		Women	
	Right hand	Left hand	Right hand	Left hand
10–19	30	35	22	19
20–29	44	42	21	20
30–39	43	41	25	25
40–49	39	38	21	22
50–59	35	33	15	14
60–69	34	31	15	14
70–79			19	16
Mean	37.4 ± 13.1	36.6 ± 12.8	19.8 ± 8.7	18.5 ± 8.3

Obtained with the Jamar dynamometer, position 3

hand, and when I say *go* you'll squeeze it as hard as possible, gradually, without sudden movements, and without changing your grip on the handle (demonstrate) until I say *stop*; then you'll relax your grip. We'll do it two more times; after 10 s I'll say *go* again. First let's do two drill tests to show me how you hold the handle; don't squeeze as tight as you can". Then begin the test saying: "this is the test. When I say *go*, squeeze the handle as hard as you can. Are you ready? *Go*! *Stop*!".

At the end of each isometric contraction, the value (in kg) indicated by the needle is recorded, and the instrument is reset before the next measurement. Finally the average of the three tests is calculated.

38.2.2 Upper Limb Strength Assessment with the Total Shoulder® Machine

The shoulder, elbow, and wrist are part of a single lesional chain, and this is the reason because is fundamental also test the near joints.

In rehabilitation, especially where athletes are concerned, strength assessment is indispensable for training program customization. Careful planning of each athlete's workload is essential for appropriate and successful muscle conditioning. Moreover, assessing the balance between strength and resistance before return to competitions is critical to avoid possible injury. The assessment tool used by our team is the Total Shoulder® machine (Technogym, Cesena, Italy) (Fig. 38.4), whose dedicated software records strength and power values in isometric tests and enables testing cuff muscles with the arm in maximum adduction as well as in 90° of abduction. Its advantages include:

- Assessment of patients with a very limited range of movement (ROM)
- Measurement of the pain threshold
- Early assessment



Fig. 38.4 Technogym Total Shoulder® machine

- Fast testing and practical operation
- Production of reliable and accurate data

Testing involves 5 s isometric contraction and 6 in maximum adduction and 6 in 90° of abduction, 12 per limb. The healthy arm is assessed first. The subject sits with the elbow on an armrest flexed at 90°. The test involves movements in internal rotation (IR) and subsequently in external rotation (ER) applied on a handle.

The subject, with the arm in maximum adduction, is asked to perform two tests at +20° IR (both IR and ER), two tests in 0 °, neutral rotation (IR and ER), and two tests at −20° of rotation (Fig. 38.5).

In the condition with the arm in 90° of adduction, the subject is asked to perform two tests in neutral rotation (both IR and ER), two tests in −45° rotation, and two tests in −90° of IR (both IR and ER) (Fig. 38.6).

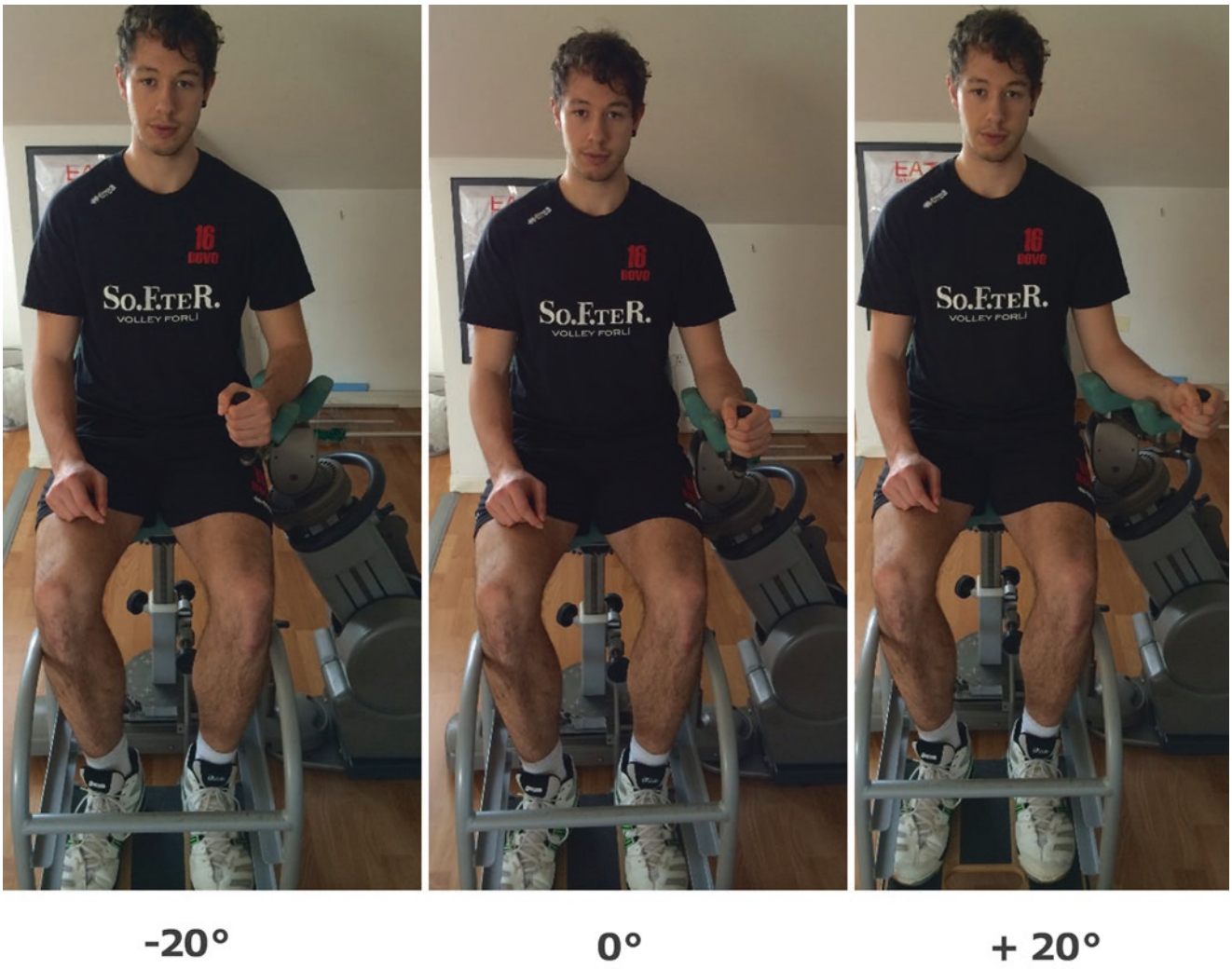
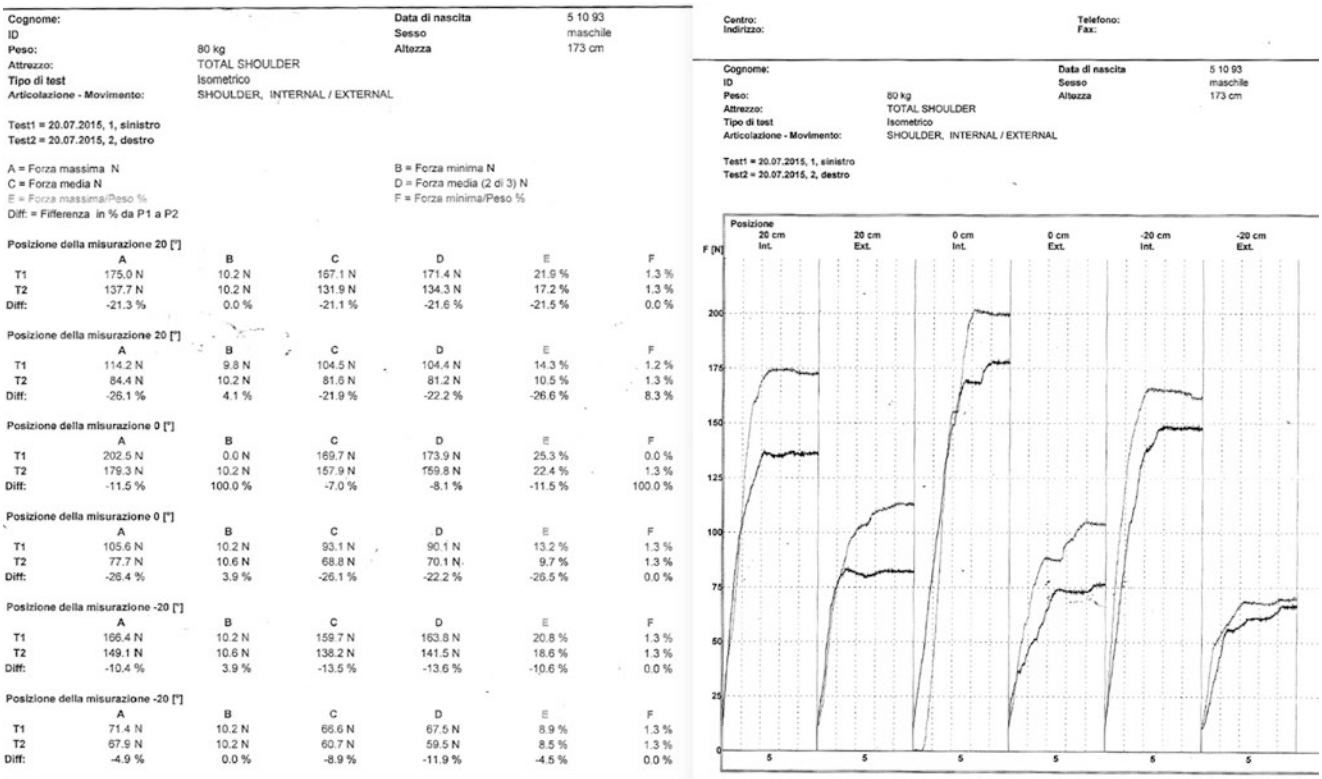


Fig. 38.5 Strength test in maximum adduction



Fig. 38.6 Strength test in 90° of adduction



Cognome:
ID
Peso: 80 kg
Attrezzo: TOTAL SHOULDER
Tipo di test: Isometrico
Articolazione - Movimento: SHOULDER, INTERNAL / EXTERNAL

Data di nascita: 5 10 93
Sesso: maschile
Altezza: 173 cm

Test1 = 20.07.2015, 1, sinistro
Test2 = 20.07.2015, 2, destro

A = Forza massima N
B = Forza minima N
C = Forza media N
D = Forza media (2 di 3) N
E = Forza massima/Peso %
F = Forza minima/Peso %
Diff: = Differenza in % da P1 a P2

Posizione della misurazione 20 [°]

	A	B	C	D	E	F
T1	175.0 N	10.2 N	167.1 N	171.4 N	21.9 %	1.3 %
T2	137.7 N	10.2 N	131.9 N	134.3 N	17.2 %	1.3 %
Diff:	-21.3 %	0.0 %	-21.1 %	-21.6 %	-21.5 %	0.0 %

Posizione della misurazione 20 [°]

	A	B	C	D	E	F
T1	114.2 N	9.8 N	104.5 N	104.4 N	14.3 %	1.2 %
T2	84.4 N	10.2 N	81.6 N	81.2 N	10.5 %	1.3 %
Diff:	-26.1 %	4.1 %	-21.9 %	-22.2 %	-26.6 %	8.3 %

Posizione della misurazione 0 [°]

	A	B	C	D	E	F
T1	202.5 N	0.0 N	169.7 N	173.9 N	25.3 %	0.0 %
T2	179.3 N	10.2 N	157.9 N	159.8 N	22.4 %	1.3 %
Diff:	-11.5 %	100.0 %	-7.0 %	-8.1 %	-11.5 %	100.0 %

Posizione della misurazione 0 [°]

	A	B	C	D	E	F
T1	105.6 N	10.2 N	93.1 N	90.1 N	13.2 %	1.3 %
T2	77.7 N	10.6 N	68.8 N	70.1 N	9.7 %	1.3 %
Diff:	-26.4 %	3.9 %	-26.1 %	-22.2 %	-26.5 %	0.0 %

Posizione della misurazione -20 [°]

	A	B	C	D	E	F
T1	166.4 N	10.2 N	159.7 N	163.8 N	20.8 %	1.3 %
T2	149.1 N	10.6 N	138.2 N	141.5 N	18.6 %	1.3 %
Diff:	-10.4 %	3.9 %	-13.5 %	-13.6 %	-10.6 %	0.0 %

Posizione della misurazione -20 [°]

	A	B	C	D	E	F
T1	71.4 N	10.2 N	66.6 N	67.5 N	8.9 %	1.3 %
T2	67.9 N	10.2 N	60.7 N	59.5 N	8.5 %	1.3 %
Diff:	-4.9 %	0.0 %	-8.9 %	-11.9 %	-4.5 %	0.0 %

Centro:
Indirizzo:
Telefono:
Fax:

Cognome:
ID
Peso: 80 kg
Attrezzo: TOTAL SHOULDER
Tipo di test: Isometrico
Articolazione - Movimento: SHOULDER, INTERNAL / EXTERNAL

Data di nascita: 5 10 93
Sesso: maschile
Altezza: 173 cm

Test1 = 20.07.2015, 1, sinistro
Test2 = 20.07.2015, 2, destro

Fig. 38.7 Test results

Data analysis (Fig. 38.7) and interpretation then enable drawing up a customized maintenance rehabilitation program or adjusting the current program for that patient.

Return to competition requires the recovering limb to achieve:

- A strength value that is equal to that of the contralateral limb (or 10% lower if it is the nondominant limb)
- IR strength that is double ER strength for movements performed with the arm adducted
- IR strength that is more than one third the ER strength for movements performed with the arm in adduction and ER
- Muscle resistance

In conclusion, shoulder testing with the Total Shoulder® and Jamar® tools provides exhaustive information on the whole upper limb and offers a significant contribution to the rehabilitation of the injured arm, which in view of the return to competitions must achieve conditions as similar as possible to those of the contralateral arm.

Besides the specific, single-muscle exercises directed at recovering the strength and resistance of the various compartments, the rehabilitation program should also include conditioning of the whole body to recover the athletic gesture. To do this, the rehabilitation therapist will select exercises with free weights and equipment, such as dumb-bells and barbells, that most resemble the athletic motion that requires training as well as further complementary exercises to strengthen the muscles that support those that are most closely involved.

38.3 Motion Analysis

The outcomes of elbow injuries, whether related to trauma or to overload, treated conservatively or surgically, can be evaluated with a number of rating scales both during and after rehabilitation, before return to ADL, amateur sports, or competitions.

Current validated rating scales to assess the upper limb are predominantly functional and are not specific for the elbow (Freehill et al. 2014). The most widely used are based on self-assessment (e.g., ASES and DASH). They focus on pain and basic functional requirements, such as dressing, undressing, and lifting a weight above shoulder level, and provide an overall limb function score. Clinician-administered scales include Constant's score and the Mayo elbow performance index. The former is specific for the shoulder and the latter for the elbow; both measure pain, ROM, and basic function. All the above scales are validated in subjects who do not practice sport.

Tools rating outcome measures in overhead athletes include the Kerlan-Jobe Orthopaedic Clinic overhead athlete score, the Timmerman-Andrews elbow score, and the Conway-Jobe

score (Smith et al. 2012). Of these, only the first has been validated. It focuses on game-related aspects such as the technical gesture and its performance, but being based on self-assessment, it is not exempt from psychological influences (Kraeutler et al. 2013). The Timmerman-Andrews elbow score is a mixed subjective (pain and function) and objective (measurement of flexion-extension and pronation-supination) rating scale.

Imaging techniques provide more reliable data on elbow ROM and stability. The telos stress device (Metax, Hungen, Germany) enables taking valgus stress X-rays to test, among other measures, the stability of the medial compartment. The joint space between the humeral trochlea and the ulnar trochlear notch (Bruce et al. 2014; Smith et al. 2011) can also be measured by ultrasound, with and without stress, using a similar method albeit with less accuracy. However, such assessments are static and do not evaluate movement alterations under the heavy workloads sustained by the elbow of professional athletes. In addition, they take into account single body segments, assessing stability in terms of mechanical resistance to passive stress, and do not consider the proprioceptive aspects or the balance of forces achieved at the end of the rehabilitation program.

Biomechanical investigations, reporting data on shoulder as well as elbow kinematics, have recently begun to be published (Fleisig et al. 2015). Only flexion-extension and pronation-supination are studied. Some biomechanical investigations use stereophotogrammetry technology, which enables acquisition and recording of the phases of movement of all body parts including compensatory movements. The apparatus uses optical technology and infrared cameras that receive the signal emitted by reflective markers applied on anatomical landmarks (Fig. 38.8).

After the calibration of 9–12 fixed cameras set around the subject, the computer recreates a virtual space or reference system. Interpolation of the signal from the cameras provides the subject's real-time 3D movement within the virtual space and shows it on the computer screen. These data can be employed in real time as biofeedback or stored and examined at a later time. The technology affords discrimination of the displacement of the individual markers, and given the biomechanical constraints of joints, the apparatus measures the angle, translation, and acceleration of all body parts. Even though it is the gold standard of biomechanical investigations, stereophotogrammetry approaches do entail some limitations: they are fairly complex in terms of hardware; camera calibration takes about 2 h, which means that they are difficult to use outside a laboratory setting; the markers must remain in view, reason why any interposed object can affect measurements; and finally they are expensive and complex to use.

An alternative technology that is spreading fast is inertial and magnetic sensing. It uses small electronic sensors (4x3x1 cm) that are applied directly on the subject at predetermined sites of the body axis (Fig. 38.9).



Fig. 38.8 Stereophotogrammetric marker positioning

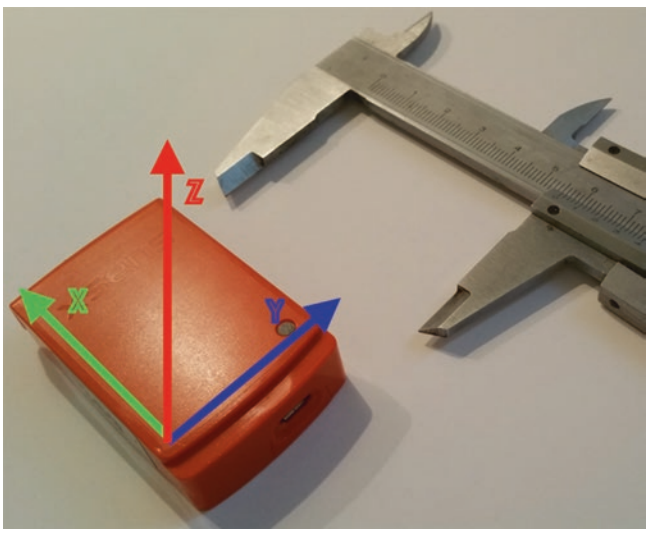


Fig. 38.9 Inertial and magnetic sensor

These devices contain an accelerometer, a gyroscope, and a magnetometer, which measure, respectively, acceleration, rotation, and displacement with respect to the Earth's magnetic axis in the three spatial dimensions. A protocol developed by biomedical engineers, based on skeletal constraints obtained from careful cadaver studies, enables integration of sensor data and calculation of the angles and accelerations of the body segment(s) examined (Cutti et al. 2008). The magnetometer provides data that are referred to the Earth's magnetic pole, thus obviating the need for recreating and calibrating a virtual reference system, as in photogrammetric apparatuses. Therefore these systems can be used anywhere, provided that there are no significant disturbances to the magnetic field. This is their major advantage compared with optical apparatuses. The intrinsic disadvantage is that the technology cannot measure the length of static segments, because unlike stereophotogrammetry systems, it can only measure sensor displacement, not the distance between them. Systems based on inertial and magnetic sensors have already been used to evaluate scapular kinematics in ambulatory settings (Parel et al. 2012) both in research and clinical assessment of overhead athletes (Pellegrini et al. 2013).

Biomechanical studies of overhead athletes have focused on scapulohumeral and scapulothoracic motion. For the elbow, the available data regards flexion-extension (sagittal plane) and pronation-supination (transverse plane). However, it is well known that the elbow conditions experienced by high-level athletes predominantly affect the medial compartment, the UCL (Bruce and Andrews 2014), and varus/valgus movements (frontal plane). It is therefore essential to understand whether inertial and magnetic technology can provide information, especially dynamic data, on these types of motion.

The carrying angle between the humeral and the forearm axis changes during flexion-extension and pronation-supination movements with considerable interindividual variability. However, extraction of the flexion-extension and pronation-supination components from the data acquired from inertial and magnetic sensors allows its real-time visualization and measurement. Several studies have described the importance of flexor muscles as elbow stabilizers (Buffi et al. 2015; Otoshi et al. 2015) in valgus deviation, especially in baseball players. Indeed it seems to be well established that the contraction of flexor and pronator muscles generates a force capable of contrasting forearm inertia, which tends to widen the valgus angle in the transition from arm cocking to arm acceleration.

Based on this theoretical construct, our group performed a preliminary study to establish whether the inertial and magnetic system provides reliable dynamic measurement of this angle. The tool we used for this study is Showlder, an innovative motion analysis system of the ShowMotion package (NCS Lab, Carpi, Italy) that is based on an inertial platform. To do this we asked some patients to perform pure shoulder IR and ER movements in supine position with the elbow flexed to 90° and the shoulder in 90° of adduction (six repetitions). Forearm inertia was increased to recreate the conditions of the pitching movement by attaching a weight of 1 kg to the wrist (Fig. 38.10).

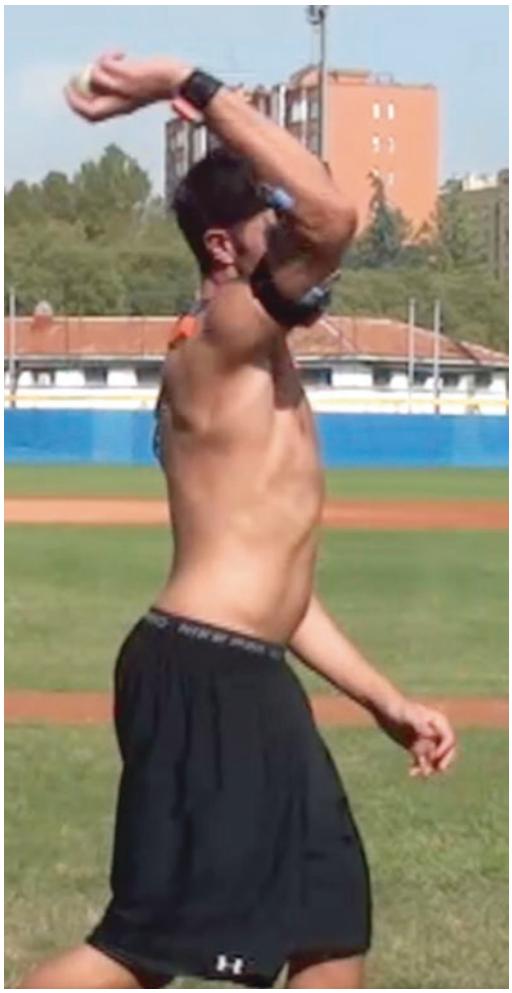


Fig. 38.10 Pitching position

The different components of shoulder and elbow movement were examined first without and subsequently with contraction of the flexor muscles using a handheld dynamometer (Figs. 38.11 and 38.12).

The maximum carrying angle was sensibly reduced in the movements performed with contraction of the forearm flexors in all repetitions. It can therefore be stated that the apparatus is not only capable of measuring changes in the carrying angle dynamically but also that the contraction of flexor and pronator muscles affects the angle. Such preliminary data open new prospects for the biomechanical evaluation of the elbow (Fig. 38.13).

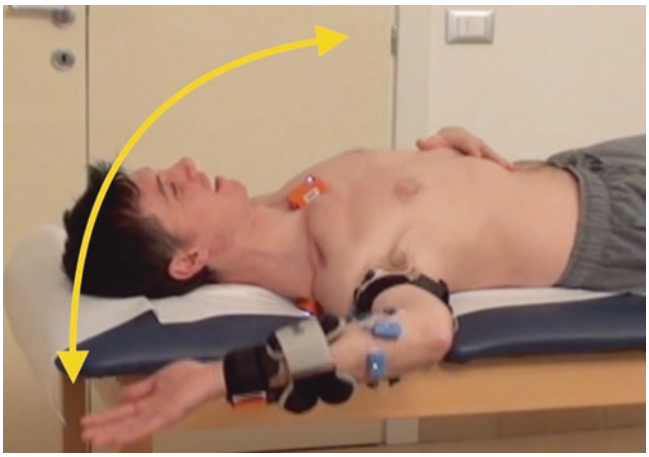


Fig. 38.11 Pitching supine simulation

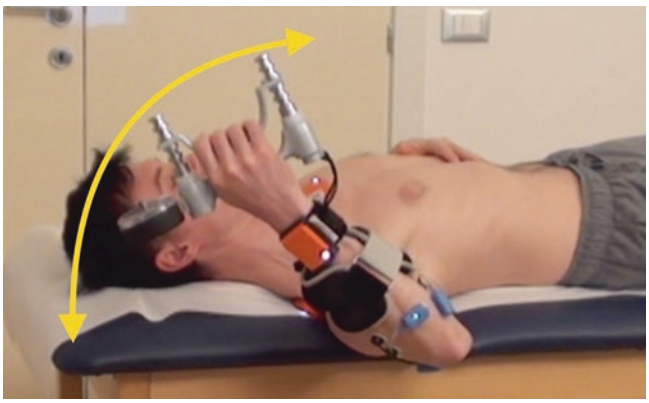


Fig. 38.12 Pitching supine simulation with weight

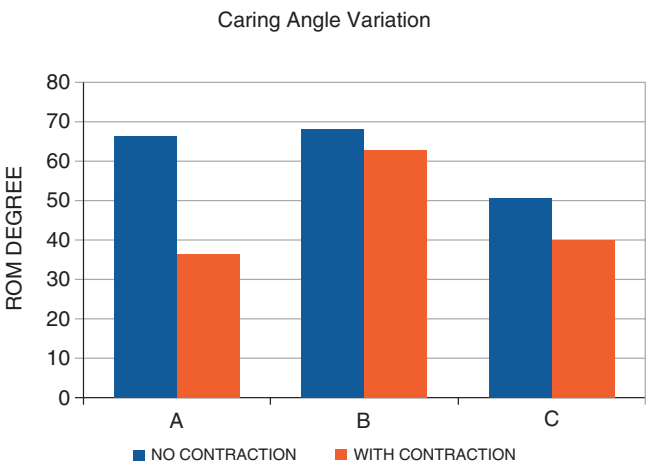


Fig. 38.13 Test results

38.4 NeuroMuscular Taping

NeuroMuscular taping (NMT) is a functional taping technique developed in 1970 that was very popular during the 2008 Peking Olympics. Since then these colored adhesive tapes have been adopted by countless athletes to improve performance or alleviate muscle and joint pain. NMT exerts both therapeutic and biomechanical actions that support the results obtained with rehabilitation.

The tapes do not release drugs; they simply consist of slightly elastic cotton and glue. The tension set by the therapist on the tape promotes compression or decompression stimuli (Sijmonsma and 1°Edizione Rivista Italiana 2010; Blow 2012; Blow 2015; Bellia 2011) to improve, respectively, joint stability or fluid circulation (lymph and blood). Decompression taping works by inducing formation of skinfolds during movement, which promotes lymphatic drainage and vascularization, reduces pain, and improves ROM and posture.

Even though training courses routinely provide information on NMT, quality data on its effect are scant; moreover reports are contrasting. Some studies, like the one by Cai et al. (2015), have found neither inhibition nor facilitation effects. As regards strength, the 2014 study by Kouhzad Mohammadi et al. (2014) involving 30 healthy individuals reported that NMT increases handgrip strength, especially if applied to the extensor muscles. In their 2013 study of patients with epicondylitis, Chang et al. (2013) reported the lack of any effect of NMT in increasing strength.

An interesting study that is in line with our notion of TNM use was published by Han et al. (2015), who found that compression taping induced marked posture improvement on the scapulohumeral hinge through elongation of the pectoralis minor and approached the scapular borders to the spine, whereas tensionless taping involved no benefit.

Our group has gained considerable experience in applying decompression taping in patients with inflammatory conditions or in the early stage of recovery from injury, to promote fluid drainage—and through it the removal of noxious substances—and fluid circulation including the transport of substances that help tissue repair. In athletes with severe instability, who cannot undergo immediate surgery, compression taping stabilizes the joint and favors the return to competitions.

38.4.1 Practical Applications

38.4.1.1 Epicondylitis

We manage this condition substantially by decompression taping, to reduce pain and inflammation by promoting fluid circulation. The technique provides a mechanical stimulus that creates space within tissue, stimulates cell metabolism, and activates the body's natural repair mechanisms through ridges that form on the skin after tape application.

Taping ensures full freedom of movement.

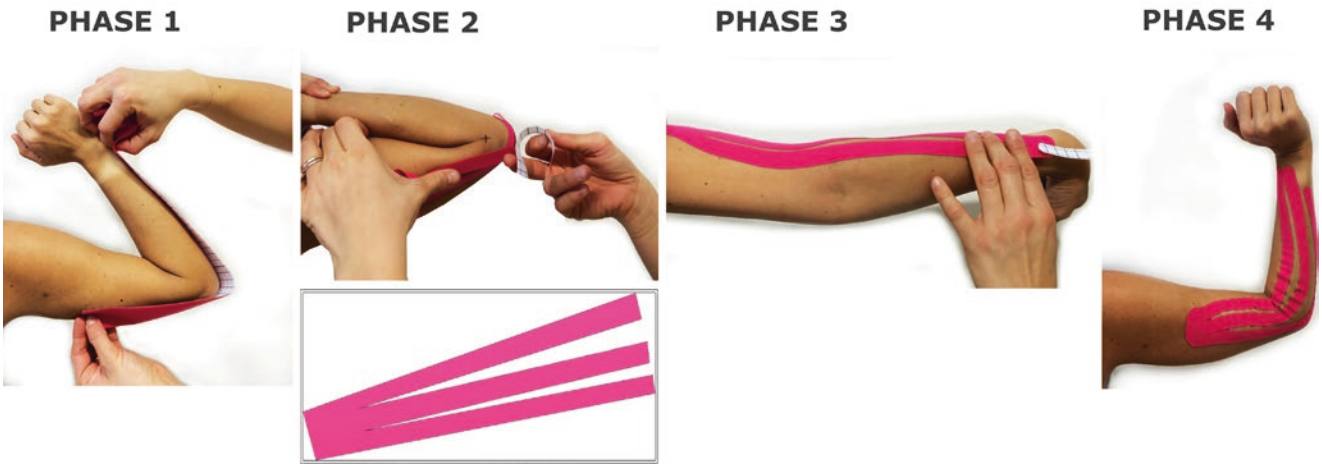


Fig. 38.14 Application for epicondylitis

Method

1. The distance from half of the triceps to the wrist is measured with the arm extended.
2. The tape is cut to measure and then into three fan strips; with the elbow bent, the central and the medial tail are applied without tension 1 cm from one another.
3. With the elbow extended, the last tail is applied from the lateral epicondyle down to the wrist about 1 cm from the next tail.
4. A correctly applied tape will show creases when the elbow executes flexion-extension movements (Fig. 38.14).

38.4.1.2 Epitrocleitis

These patients are also managed by decompression taping to support drug treatment and rehabilitation.

Taping ensures full freedom of movement.

Method

1. The distance from half the biceps to the wrist is measured with the arm extended.
2. The tape is cut to measure and then into three fan strips; with the elbow and wrist extended, the central tail is laid along the medial epicondyle, following the flexor carpi ulnaris up to its insertion, where it is attached.
3. With the elbow and wrist flexed, the distal tail is applied about 1 cm from the central tail.
4. With the elbow and wrist extended, the medial tail is applied about 1 cm from the central tail.
5. A correctly applied tape will show creases when the elbow flexes and extends (Fig. 38.15).

38.4.1.3 Olecranon Bursitis

These patients are also managed by decompression taping to support drug treatment and rehabilitation.

Taping ensures full freedom of movement.

Method

1. A 30 cm length of tape is cut, and three tails are obtained.
2. The base of the tape is applied above the tricep insertion.
3. With the elbow and wrist flexed, the three tails are applied without tension close to the lateral and medial condyle and olecranon.
4. A correctly applied tape will induce skin creases when the elbow executes extension movements (Fig. 38.16).

38.4.1.4 Ulnar Collateral Ligament Injury

For UCL lesions we apply compressive and corrective taping to stabilize the joint. Since the tape is elastic, it does not hamper the athletic gesture as would a stiff bandage but partially limits extension and valgus movements.

Method

1. About 8 cm of black tape and about 20 cm of pink tape are cut.
2. With the elbow in maximum varus position, the central portion of the smaller tape is applied with 80% tension and the end portions without tension; the base of the tape is applied about 3 cm above the epicondyle and reaches to about half the forearm.
3. With the elbow flexed and the forearm pronated, the base of the pink tape is applied without tension at the level of the mid triceps, and the remaining portion is given 80%

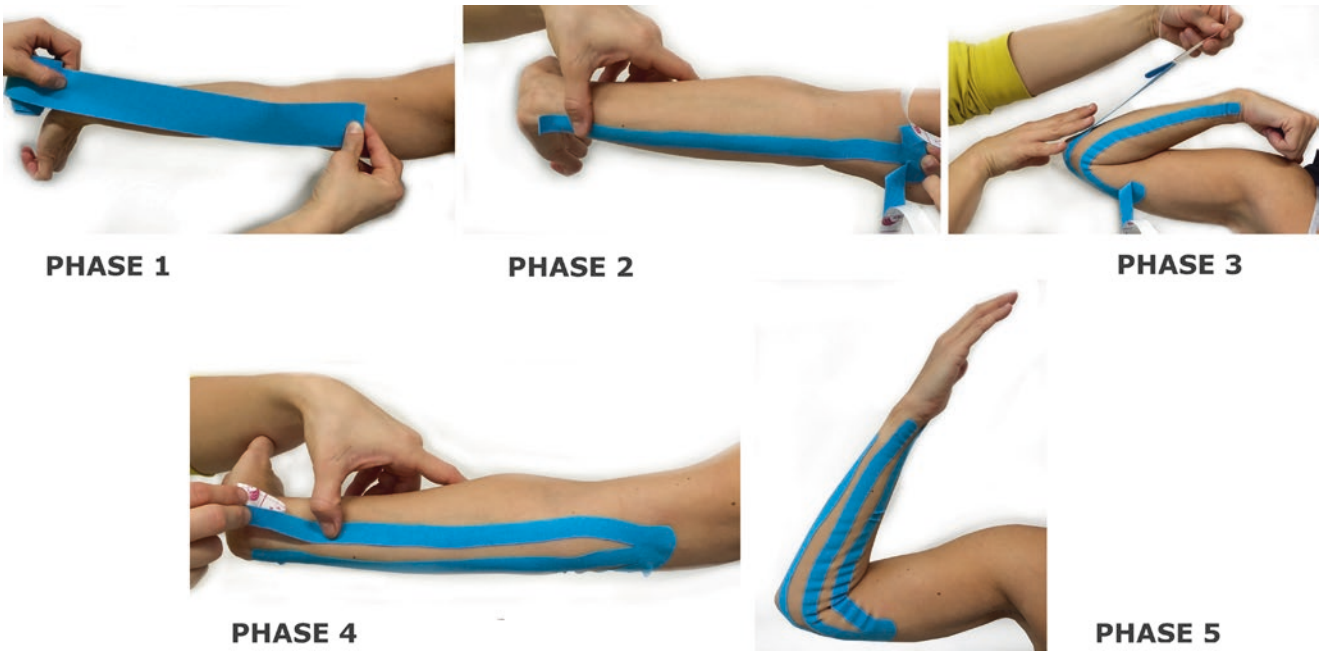


Fig. 38.15 Application for epitrocleitis



Fig. 38.16 Application for olecranon bursitis



Fig. 38.17 Application for ulnar collateral ligament injury

tension over the medial epicondyle until mid-forearm; then the tail is attached to the forearm without tension.

4. With this technique there are no creases, because the tapes are tensioned to limit valgus and, partly, extension movements (Fig. 38.17).

38.5 Neoprene

Neoprene orthoses are widely used in upper limb rehabilitation. The literature regarding the rehabilitation of the hand and wrist compartment describes several types, including static, dynamic, functional, and protective devices (Punsola-Izard et al. 2001; Punsola-Izard et al. 2013; Colditz 1999).

The softness and elasticity of neoprene enable realization of comfortable sleeves that adapt to arm anatomy while contributing to repair and scar processes (Jobe et al. 1996), besides providing a constraint capable of limiting edema. The neoprene base is usually reinforced with parts in thermoplastic material or neoprene to support the segment or limit movement in the prescribed direction.

In elbow rehabilitation neoprene is used as the basis of functional immobilizers, to protect inflamed body parts or ones that are healing; they are therefore especially indicated in the final progressive loading stage and throughout the recovery of total load.

The throwing motion of some sports generates considerable stress on the medial ligament complex of the elbow. As the athlete gradually returns to training, it is essential to protect the healing process to prevent the forces, which are often applied at a velocity exceeding the pace of physiological tissue repair, from inducing progressive microscopic lesions (Colditz 1999) that would involve regression to a fresh inflammatory phase.

The neoprene sleeve must be tailor made and has two appropriately shaped rods on the sides. Its adherence to the arm coupled with the lateral reinforcements absorbs part of the stress and protects the elbow joint complex from potentially harmful stimuli (Fig. 38.18).

Functional orthoses must ensure freedom of nonhazardous movements, limit those that induce stress on healing tissues, and be comfortable, discreet, easy to wear, and not excessively bulky. Neoprene is an ideal material for these purposes, and it is increasingly used in rehabilitation not only of the elbow but also of the whole upper limb.

In patients with ligament lesions involving both the medial and the lateral compartment, we usually apply stiff rods with an extension block to maximize varus, valgus, and extension stability (Figs. 38.19 and 38.20).

The technique reduces pain and the patient's apprehension, which in our view is a key element in the return to competition. Injuries are common events in all sports, but sometimes they affect the athlete very negatively. Even experienced, high-level athletes admit to fearing the time of their return to games after an injury. Psychological blocks due first and foremost to fear can therefore prevent learning new movements or the correct execution of acquired gestures. It is therefore essential to understand the athlete and their psychological state to promote an easier return to competitions. In our opinion thorough warm-up, reconditioning, and the adoption of adequate supports like customized orthoses are critically important not only for the athlete's body but also for their psychological health.



Fig. 38.18 Neoprene orthoses with rigid splints



Fig. 38.19 Stiff rods with an extension block



Fig. 38.20 Technical movements in orthoses

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Part IV

Other Rehabilitation Techniques

Rehabilitation in Swimming Pool

39

Marco Biondi, Silvia Capone, and Francesco Inglese

39.1 Introduction to "Hydrokinesitherapy"

At present there is a general consensus in considering water as an element favoring an optimal muscle training and an early functional recovery in patients suffering from diseases affecting the muscular system in a primary or secondary mode. Especially in rehabilitation, the effectiveness of the hydrokinesis has been variously investigated by the world scientific literature, and water qualities are widely exploited in the conservative rehabilitation protocols for various pathologies of musculoskeletal origin (low back pains, tendinitis, degenerative muscle tendon pathologies, etc.) and in the postsurgical orthopedic protocols of the various anatomical zones (elbow, shoulder, spine, hip, knee, ankle).

In acute inflammatory tendon pathologies, mild repetitive motions for a long time (at least 20 min of activity) allow water aerobic work in the absence of pain, providing an initial therapeutic muscle exercise: the increase of flow in the blood microcirculation in zones, sites of inflammation, allows a lower stasis of liquids, decreasing the painful tensions on the surrounding tissues. The pressure of the buoyancy in the water, which counterbalances the weight force, leads to a relaxation of the toned antigravity musculature that often is contracted and painful in patients with various pain syndromes of orthopedic origin. The improvement of the pain symptomatology allows a muscular exercise enough to prevent the secondary damage of the possible immobility of the acute phase.

In addition, in the presence of edema and hematoma, for example secondary to traumatic injury, the pressure of buoyancy of water gives good help to circulation and the reabsorption of liquids: the patient, in the vertical poolside, performs specific aerobic therapeutic exercises, using the properties of uniformity on tissues and increasing the gradient according to the depth of the buoyancy. This improves the circulatory flow from the periphery of the body to the heart, favoring the reabsorption of the edema.

The work on the water, especially when hot (minimum 30 °C), allows a reduction in the rate of firing of nociceptors and a more general relaxation of the body muscles, thereby relieving pain syndromes related to stiffness and muscle spasms, resulting in even ordinary exertion (e.g., in athletic patients) or secondary to other degenerative or inflammatory diseases.

The general considerations about the advantages of working in water become even more evident in the case of patients undergoing surgery. The reduction of the weight force, the support offered by the water on parts of the body, the absence of shear forces during the exercise, and the possibility of a progressive muscular work, initially with minimal intensity, allow the patient to work on the maintenance work of muscular tone and tropism and on functional motor recovery of the part operated before its time, even 2 weeks in advance of the exercise in a rehabilitation gym. As for the district of the upper limb, for example, the French school even proposes works of mobility in the water already in the second day after the surgical interventions, obviously placing particular care to the protection of the area of the surgical cut through the adoption of specific waterproof bandages.

Even the proprioceptive feedback offered by the water becomes important and facilitates the motor and functional recovery of the upper limb, especially when the patient is an athlete. In fact, in the case of sporty patients (tennis players, golfers, and in general sporty overhead athletes), training in partial or total immersion provides an added value to the therapeutic path designed to the return of the athlete to the field: the sporting gesture can be early simulated in diving where the water properties (absence of gravity and shear forces, support of the limbs and work at low angular velocities, etc.) also decrease the risks related to the intensity of the gesture itself. Remember that the friction in water proportionally increases at the square of the speed with which the movement takes place: in the advanced stages of the rehabilitation process, the demand for fast execution of therapeutic exercise, or simulated

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gesture, and the use of tools, such as paddles or flippers (the surfaces of which further increase the friction with the water), allow an important training of the muscles, in the presence of minor joint stress and decreased pain. Furthermore, in the long run, the properties of viscosity and proprioceptive feedback offered by the liquid can be exploited in the structuring of high-intensity exercises, including the use of sports equipment directly in immersion.

In conclusion, the water is to be considered an important tool during all phases of the rehabilitation and functional recovery of the patient, ultimately always allowing a global work that brings benefits simultaneously not only to the part of greatest clinical interest but to the welfare of "patient person" in his/her entirety.

39.2 The Benefits of Rehabilitation in Water

Over the years the hydrokinetic has spread, thanks to the benefits of the movement performed underwater. All the positive aspects of motor activity in the water are the logical consequence of the principles offered by this element. The principles should be exploited by the physiotherapist to recover motor skills lost from the patient.

Here is a list of some of the most useful principles:

The Push of Buoyancy Among the many benefits, it is perhaps the most important. The push of buoyancy is increased or decreased in relation to the level of immersion of the body. The force generated by this pressure opposes the gravity: we can use the two forces increasing or decreasing one to the other, or increasing them simultaneously. The higher the immersed part, the lower the effect of the force of gravity: all the degenerative joint diseases will benefit. At the same time, after an injury or intervention, we can monitor the effect given by the return of the load by gradually reducing the percentage of immersion of the body. In addition to the level of immersion, the push of buoyancy can be increased by the use of floating belts (or floats in general) and by the introduction of air into the lungs; on the contrary the gravity will be reinforced by the positioning of weights, as anklets and belts. The positioning of weights and floats, in the various body parts, will be in relation to the disease and the effect to be obtained. The decrease of the load also favors a reduction of the muscular-articular coordinative constraints typical of land environment, with subsequent attenuation of muscle tone.

The reduction of the sense of position, registered by the immersed segments, stimulates new coordination skills, certainly set in a different situation compared to the usual one, but however able to widen the baggage of proprioceptive experiences (principle of motor transfer) of the patient.

Variations of the Thermal Degree The water is able to absorb or yield large amounts of heat.

Depending on the temperature, we can cause sedation or tonic effects: the heat will have a relaxing effect on skeletal musculature and the contractions reflected. The temperature favors a vasomotor action on the circulatory network, producing a vasoconstriction (positive effect on the absorption of edema or venous stasis) or vasodilatation (recovery of muscle contractures).

Hydrostatic Pressure Water exerts a pressure on the body immersed directly proportional to the depth (Stevin's principle); at the same depth, the pressure is transmitted with the same intensity in all directions (Pascal's principle). The effect of the pressure, uniformly at the same depth, and gradual, in relation to the level of immersion of an upright subject, favors the venous return in the lower limbs that normally flows against gravity (effect of "elastic stocking").

Another effect that pressure exerts on the skin is related to the reduction of pain. The cutaneous pressure receptors are owned by afferent fibers of large caliber which at central level inhibit painful stimuli from the deeper tissues: for this reason the simple immersion in water relieves pain.

Hydrodynamic Resistance The resistance that water opposes to the movement, under equal conditions, is directly proportional to the square of the speed (double speed = quadruple resistance).

If you walk slowly in water, the resistance of the fluid can be 5–6 times higher than air, and if you run fast, the resistance increases up to 40 times more than air. In the early stages of rehabilitation, in the presence of a very weak musculature, the slow movement is assisted by the reduced gravity; subsequently, with the recovery of the tone-trophism, the displacement speed will increase, countered by a resistance always proportionate and compared to the capacity of each individual patient. The movement in the water, in addition, is less traumatic, since the resistance is distributed over the entire lever, thus reducing the cutting forces. The movement in open kinetic chain, in the absence of tools (elastic, floats, etc.), is devoid of the eccentric phase, phase certainly important, but excessive in the initial stages of rehabilitation.

39.3 General Benefits of Therapeutic Exercise in Water

- Reduced workload
- Ease of execution of the movements
- Benefits associated with the movement
- Relaxation of the musculoskeletal system
- Atraumatic movements
- Increased joint mobility due to the reduction of the tone

- Possibility of early mobility
- Improvement of local and general circulation
- Reduction of edema and effusions
- Reduced cutting forces on the articular heads
- Resistance proportionate to the patient
- Psychological positive effects

39.4 Assumptions of Rehabilitation in Water

Into the Water: When to Start?

There are several rehabilitative programs that encourage access to the water of postsurgical patients, in different times between them. There are mainly two philosophies that differentiate schools of thought. A first interpretation provides entry into the water 2–3 days after surgery (Lyons school, American school). In this case, the wound must be protected with appropriate patches to prevent the direct contact with the water. A second interpretation allows the patient to enter the water from 30° to 35° day after surgery (some Italian realities). The early entry reduces the risk of incurring in joint capsula stiffness (unfavorable complication, because it increases excessively recovery times and, in some cases, can cause the patient a new surgical intervention); at the same time, it exposes the wound to possible infection and, worse still, submits the surgical suture (or bone fractures) at risk of nonhealing or nonunion.

The "postponed" entry does not expose the wound and protects the suture or osseous callus: the percentages of stiffness after surgery, however, may increase. The two ways of thinking manifest positive and negative aspects, which can confirm or advise against the different timing. To choose the right time of entry into the water, we suggest to resort to logic. Theoretically, all patients could begin hydrokinetic from the 20th postsurgery day, because after 15 days the stitches are removed and within the next 5 days the wound is completely closed. There are, however, indications relating to the patient's pathology. In the surgical operations considering the healing of sutured tissues, it is correct to "wait" to avoid unpleasant incidents.

Patients affected by primary or secondary rigidity and all patients who do not have to wait for the healing of "noble" structures can and must begin idrokinesis therapy as soon as possible. It is essential to follow specific precautions starting idrokinesis exercises in early times, even for the types of patients mentioned above.

Initially, the session in the water must be of limited duration, around 10–20 min, while the movements should be passive, performed by the operator or by the contralateral arm of the patient. The rehabilitation program will include an increase of time of the session up to 50–60 min and an integration with therapeutic exercise aimed at recovering the active motion, the muscle strength, and the coordination of the movement.

39.5 Introduction to the Stiffness of the Elbow

In literature, the rigidity of the elbow has been classified in various ways, but the common feature is the contracture of the joint capsule (Jupiter et al. 2003).

Contracture of the joint capsule is a frequent complication in fractures, dislocations, trauma, and elbow surgery in general (Ouyang et al. 2013; Müller et al. 2013; Hart et al. 2011; Søjbjerg 1996).

Elbow stiffness is defined as the limitation of the joint mobility of the elbow more than 30° in extent and/or a decrease of less than 120° (Søjbjerg 1996). Although the limitation of pronation-supination is often involved in rigidity, it is not considered in the classification of the stiffness (Søjbjerg 1996).

The rigidity of the elbow limits the functionality of the hand, highly dependent on the flexion-extension of the elbow. If a stiffness is grade 4 or worse, ankylosis of the elbow severely limits the activities of daily life (Hart et al. 2011); already a 50% reduction of the mobility of the elbow leads to an 80% limitation of the functionality of the upper limb (Søjbjerg 1996).

The treatment of the rigidity of the elbow is difficult, especially when the rigidity is severe and worse if in conjunction with problems in the consolidation of bone fractures (Ouyang et al. 2013).

Prevention is the key to prevent the complication of elbow stiffness (Issack and Egol 2006).

Current scientific evidence supports, in addition to initial treatment with physical therapy and static progressive splinting (Issack and Egol 2006; Schwartz 2012), also the need of a treatment/self-treatment of progressive static stretching for 30 min three times a day in all directions as the first prevention of posttraumatic stiffness of the elbow (Müller et al. 2013).

Rehabilitation should therefore begin as soon as possible and be continued for at least 6 months, a period that is considered critical for the recovery of the ROM (Giannicola et al. 2014).

If conservative treatment fails, the surgical approach should be considered (Müller et al. 2013) but only after a minimum of 6 months of conservative treatment and the patient's awareness of the need for a proper and early rehabilitation program after surgery to prevent recurrence of stiffness (Issack and Egol 2006).

In the case of complex instabilities of the elbow, according to the study of Giannicola et al., 70% of patients recover a functional mobility between the 3rd and 6th month: the flexion in general has a slower recovery than the other movements (Giannicola et al. 2014). An early rehabilitation program is considered also in this case, one of the key points to prevent the onset of secondary joint stiffness to the long period of immobilization (Giannicola et al. 2014).

The closed reduction followed by a short period of immobilization in tutor is generally accepted as the treatment of simple elbow dislocations (Kesmezacar and Sarikaya 2010). The immobilization brace can be extended for 3 weeks (Kesmezacar and Sarikaya 2010). The complexity of the joint, muscle, and neuromotor elbow makes yet frequent the problem of joint stiffness especially as a result of prolonged immobilization (Fusaro et al. 2014). According to the study of Kesmezacar et al., most patients complain, following a period of immobilization, feeling of stiffness to the elbow, pain during labor and sports activities, and mobility limitation (Kesmezacar and Sarikaya 2010).

Where it comes to the surgical solution, arthrolysis always associated to an early and targeted rehabilitation program after surgery can improve joint function while ensuring stability of the elbow (Zhang et al. 2009).

According to some authors, in the specific case of the intercondylar distal humerus fracture, the limitation of mobility is a frequent event even regardless of the rehabilitation program conducted. The main causes of rigidity are the formation of heterotopic ossifications and the excess of the osseous callus. In these cases the surgical approach leads generally good results when combined with a proper and early rehabilitation program that averts the possibility of relapse (Koh et al. 2013). Even after elbow surgery, in fact, heterotopic ossification is the most common extrinsic cause of contracture of the elbow and can lead to an important stiffness up, rarely, to complete ankylosis. Hypertension, obesity, and lack of intraoperative anterior transposition of the ulnar nerve are considered negative predictive signs for the therapeutic outcome. Surgery combined with postoperative prophylaxis and a program of early structured rehabilitation constitute an effective approach to the treatment of heterotopic ossification in the elbow (Salazar et al. 2014).

The mobilization of the elbow following a trauma/surgery must therefore always be begun as soon as possible and the effectiveness of rehabilitation is still strongly conditioned by the "compliance" of the patient (Fusaro et al. 2014).

Although in literature a consensus is evidenced concerning the appropriate surgical approach in the treatment of fractures of the elbow, but not concerning the period of postoperative immobilization, the type of exercises to be taken for the recovery of joint function and the measure of efficacy of the treatment in the recovery of the ROM (Lee et al. 2012), in any case early mobilization of the elbow has to be considered always important in the recovery of mobility and function of the elbow (Chien et al. 2010).

39.6 The Therapeutic Exercise in Water for the Elbow

As reported in the literature (Issack and Egol 2006; Giannicola et al. 2014; Chien et al. 2010), in the rehabilitation of the elbow, posttraumatic or following surgery, the recovery of passive mobility of the joint and preventing the onset of the secondary joint stiffness through early and passive/or passive self-assisted mobilization is fundamental.

In the water you can use various tools to implement an effective self-assisted mobilization of the elbow by the patient: a ring of soft rubber may be useful to limit the compensation at the level of the glenohumeral joint during flexion-extension movements of the elbow, assisted by the healthy limb through the use of a stick; the possible use of a float on the stick can facilitate the phase of bending and/or to offer a first resistance for an initial active work of the brachial triceps in extension (Figs. 39.1 and 39.2). The same self-mobilization in flexion-extension can be done with the forearm in supination, in pronation, or in an intermediate position to change the reciprocal positions of the joint during exercise.

In a second time, simulating a gesture similar to "row" will complicate the exercise of joint mobilization.

Still by means of a stick, it is possible to implement a self-assisted mobilization in prono-supination, keeping the elbows flexed to etch selectively on the elbow and avoid the



Fig. 39.1 Exercise of bimanual flexion-extension with stick and circular float above the elbows to limit compensation



Fig. 39.2 Exercise of bimanual flexion-extension with stick and circular float above the elbows to limit compensation



Fig. 39.3 Self-assisted mobilization in pronation and supination

involvement of the shoulder joints, with compensation possibly more limited by the use of rubber circle (Figs. 39.3 and 39.4).

As the mobility improves, you can structure more complex exercises, for example, in horizontal floating, performing flexion-extension movements, the patient will exercise a progressive active muscle engagement of the entire upper



Fig. 39.4 Self-assisted mobilization in pronation and supination

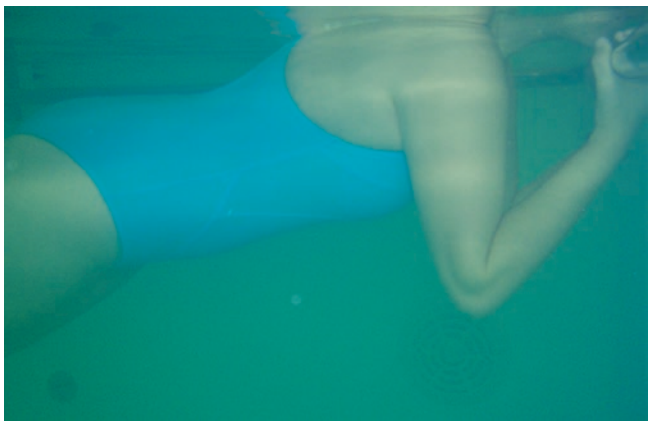


Fig. 39.5 Patient in horizontal floating during an exercise in self-assisted active flexion-extension in pronation and supination of the forearm

limb, always alternating positions in pronation and supination of the forearm (Figs. 39.5, 39.6, 39.7, and 39.8).

You can structure subsequently selective strengthening muscle exercises for the various muscle components of the upper limb through the use of resistances such as dumbbells and floats, boards, and paddles of various shapes and sizes.

With the elbow close to the side, using a float as resistance, you can train the brachial triceps in an alternating concentric and eccentric way: clutching the float will involve epicondylus and epitrochlear muscles to provide greater stability of the elbow in laterality, especially in postsurgical cases or related to conservative problems of joint instability; instead fastening the float to the wrist will preserve epicondylus and epitrochlear muscle by excessive involvement in cases of acute or subacute Golfer's elbow/epicondylitis (Figs. 39.9, 39.10, and 39.11).



Fig. 39.6 Patient in horizontal floating during an exercise in self-assisted active flexion-extension in pronation and supination of the forearm



Fig. 39.7 Patient in horizontal floating during an exercise in self-assisted active flexion-extension in pronation and supination of the forearm

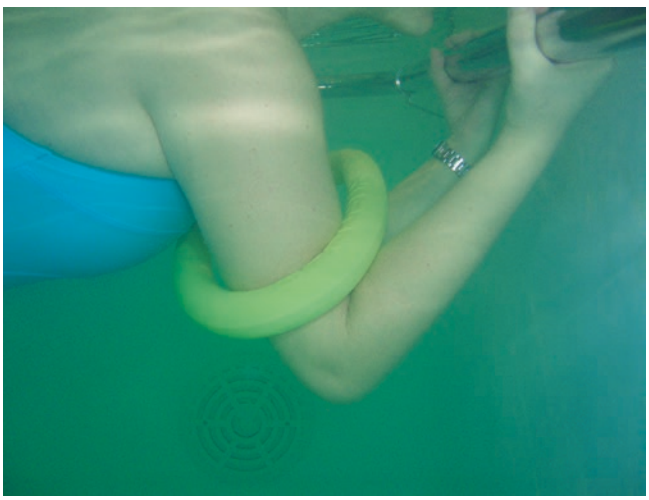


Fig. 39.8 Exercise in self-mobilization with floating guide in patient's horizontal floating

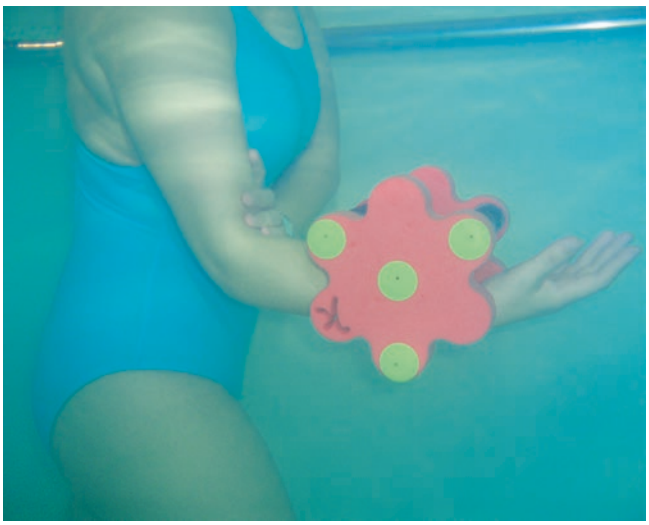


Fig. 39.9 Exercise of strengthening triceps muscle with a float attached to the wrist to avoid overloading the epitrochlear/epicondylus muscles

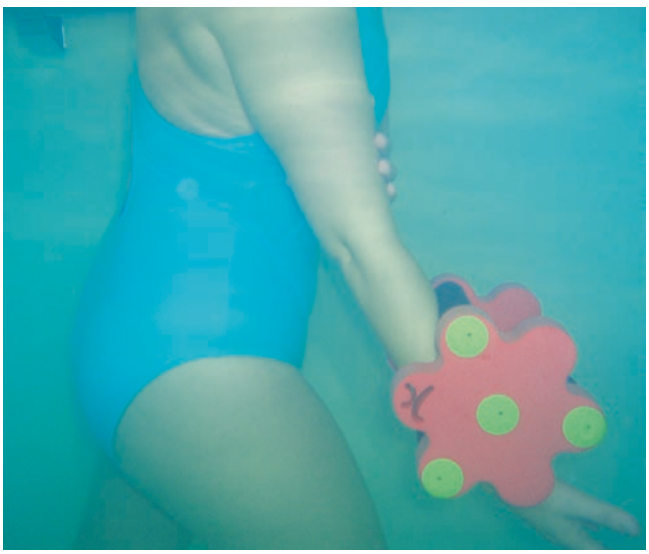


Fig. 39.10 Exercise of strengthening triceps muscle with a float attached to the wrist to avoid overloading the epitrochlear/epicondylus muscles

In the early stages of the recovery of painful problems of instability of the elbow, you can also propose exercises of active mobilization of the upper-level glenohumeral joint and simultaneous maintenance of stability of the elbow by an isometric contraction in extension against resistance float (Figs. 39.12 and 39.13).

The water also provides an ideal environment for the training of proprioception: putting a floating board under the palm of a hand, you can ask the patient to control the board during selective flexion-extension movements of the elbow or abduction-adduction movements of the shoulder or



Fig. 39.11 Exercise of strengthening triceps muscle with a float attached to the wrist to avoid overloading the epitrochlear/epicondylus muscles

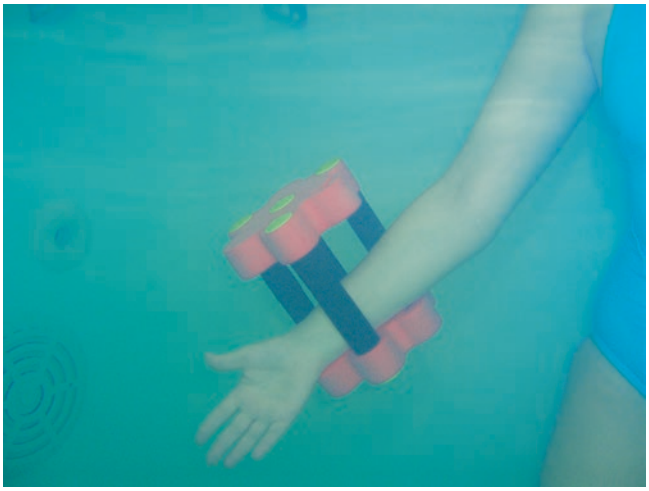


Fig. 39.13 Isometric stabilization of the elbow in extension combined with adduction-abduction movements at the glenohumeral joint level

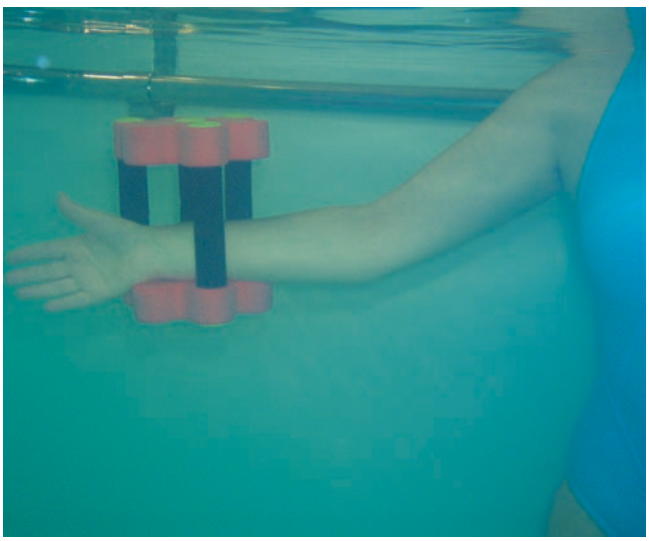


Fig. 39.12 Isometric stabilization of the elbow in extension combined with adduction-abduction movements at the glenohumeral joint level

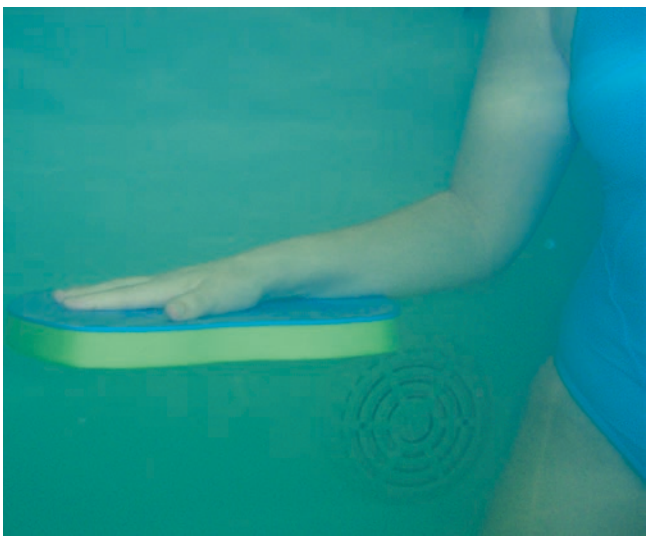


Fig. 39.14 Proprioceptive exercises/reinforcement using a floating board

flexion-extension of the wrist to the elbow extended (Figs. 39.14, 39.15, and 39.16).

As more complex and refined proprioceptive exercise, you can then propose to the patient to control a ball positioned above the board kept afloat during movements of triple flexion-extension of the upper limb immersed in water (Figs. 39.17 and 39.18).

In the final stages of rehabilitation, you can ask to perform acts of bimanual rowing, with the forearm in pronation or supination and body in horizontal floating (possibly with feet tied to the handrail of the pool) maintaining a stick in immersion to which you could possibly apply floating resistances to increase the muscular strengthening and control of the movement (Figs. 39.19, 39.20, 39.21, and 39.22).



Fig. 39.15 Proprioceptive exercises/reinforcement using a floating board



Fig. 39.16 Proprioceptive exercises/reinforcement using a floating board

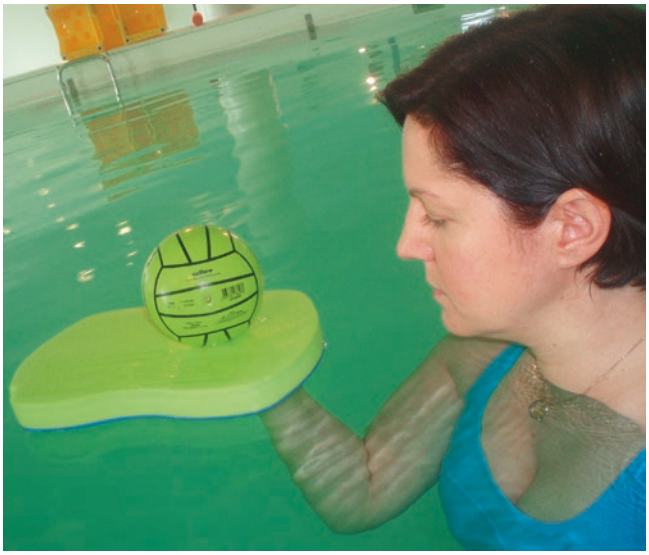


Fig. 39.17 Proprioceptive exercise in triple flexion-extension of the upper limb in immersion through the use of a floating board and a ball



Fig. 39.18 Proprioceptive exercise in triple flexion-extension of the upper limb in immersion through the use of a floating board and a ball



Fig. 39.19 Exercise of bimanual "rowing" against floating resistance in horizontal floating of the patient

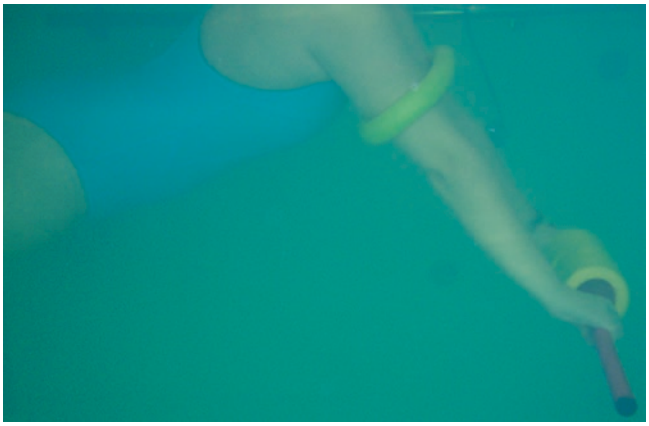


Fig. 39.20 Exercise of bimanual "rowing" against floating resistance in horizontal floating of the patient



Fig. 39.21 Exercise of bimanual "rowing" against floating resistance in horizontal floating of the patient

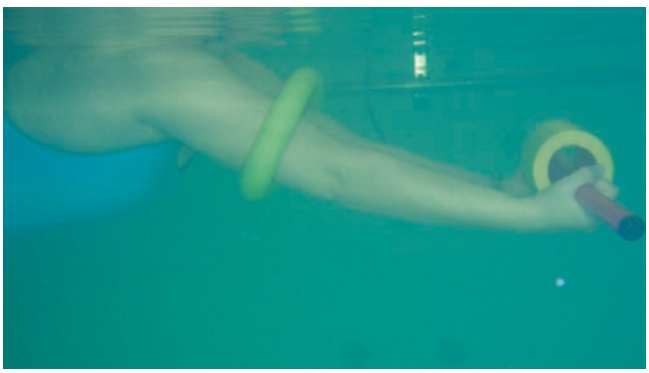


Fig. 39.22 Exercise of bimanual "rowing" against floating resistance in horizontal floating of the patient

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The Role of Osteopathic Medicine

40

Marco Petracca and Silvia Di Giacomo

40.1 Osteopathy and Osteopathic Medicine

The World Health Organization considers osteopathy (also called osteopathic medicine) a health-care practice included in the board of Traditional and Complementary Medicine (T&CM).

T&CM practices include medication therapy and procedure-based health-care therapies such as herbal medicines, naturopathy, acupuncture, and manual therapies such as chiropractic, osteopathy, as well as other related techniques including qigong, tai chi, yoga, thermal medicine, and other physical, mental, spiritual, and mind-body therapies.

T&CM practitioners can be TM practitioners, complementary and alternative medicine (CAM) practitioners, conventional medicine professionals, and health-care workers such as doctors, dentists, nurses, midwives, pharmacists, and physical therapists who provide TM/CAM services to their patients (World Health Organization 2013).

Osteopathy—from the Greek *osteon* (bone) and *pathos* (suffering, disease, feeling)—was developed by Andrew Taylor Still, a physician and surgeon in the United States of America in the mid-1800s, who established the first independent school of osteopathy in 1892.

It relies on manual contact for diagnosis and treatment and can be considered a form of manual medicine and a CAM.

Osteopathic health care and philosophy are based on the principle that the structure and functions of the body are closely integrated and that a person's well-being is dependent upon the neurological, musculoskeletal, and visceral structures working in balance together.

This holistic approach to patient care and healing is based on the concept that a human being is a dynamic functional unit, in which all parts are interrelated and which possesses its own self-regulatory and self-healing mechanisms.

One essential component of osteopathic health care is osteopathic manual therapy, typically called osteopathic manipulative treatment (OMT), which refers to an array of manipulative techniques that may be combined with other treatments or advice, for example, on diet, physical activity and posture, or counseling.

The practice of osteopathy is distinct from other health-care professions that utilize manual techniques, such as physiotherapy or chiropractic, despite some overlapping in the techniques and interventions employed. As a hands-on approach to patient care, osteopathy has contributed to the body of knowledge of manual medicine and CAM (World Health Organization 2010).

Over the first half of the twentieth century, osteopathic practice rapidly spreads all over the world. Osteopathic health care is now provided in every continent except Antarctica and is practiced in more than 50 countries.

Globally, two professional streams have emerged, largely due to different legal and regulatory structures around the world:

- Osteopathic physicians (practicing osteopathic medicine) are doctors with full, unlimited medical practice rights and can specialize in any branch of medical care (mainly in the US system).
- Osteopaths (practicing osteopathy) are primary contact health providers with nationally defined practice rights and do not, for example, prescribe pharmaceuticals or perform surgery.

Recognition, education, and regulation of osteopathic practitioners have developed differently around the world, influenced by the specific cultural, economic, legal, and political factors of individual countries (Osteopathic International Alliance 2014).

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40.1.1 Principles and Models

The concept of osteopathy is based on its philosophy, principles, and models.

The 2011 Glossary of Osteopathic Terminology includes the following definition of osteopathic philosophy:

A concept of health care supported by expanding scientific knowledge that embraces the concept of the unity of the living organism's structure (anatomy) and function (physiology). Osteopathic philosophy emphasizes the following principles:

1. The human being is a dynamic unit of function.
   The human body does not function as a collection of separate parts but rather as an integral whole. Obviously, the body does consist of parts—the heart, the lungs, the musculoskeletal system, and so forth—all working to benefit the organism in totality.
   Uniting the body's parts is the fascia, a deep fibrous tissue investing the muscles and organs and acting as a ground substance to support and unite the whole body from head to foot.
2. The body possesses self-regulatory mechanisms that are self-healing in nature.
   The body has the inherent capacity to defend and repair itself. When normal adaptability is disrupted or when environmental changes overcome the body's capacity for self-maintenance, disease may ensue.
3. Structure and function are interrelated at all levels.
   Any body part performs a function dictated by its structure. As structure governs function, similarly, abnormal structure brings about dysfunction. Abnormal function also results in alteration of related structures.
4. Rational treatment is based on these principles (Educational Council on Osteopathic Principles of the American Association of Colleges of Osteopathic Medicine 2011; DiGiovanna et al. 2004).

According to its philosophy and principles, osteopathy is a patient-centered system of health care, rather than disease centered.

The practical application of the principles is described by several models of structure-function relationships that osteopathic clinicians use to influence the gathering of diagnostic information and the interpretation of the significance of neuro-musculoskeletal findings in the overall health of the patient.

The following five models of structure-function guide the osteopathic clinician's diagnosis and treatment of the patient. These models are (European Federation of Osteopaths & Forum for Osteopathic Regulation in Europe 2012):

1. Biomechanical model (effects of postural and biomechanical factors on the patient's ability to compensate for stressors or illness)
2. Respiratory-circulatory model (importance of the respiratory-circulatory system in maintaining proper cell and tissue function)
3. Neurologic model (influence of the nervous system on physical, cognitive, and emotional health)
4. Metabolic energy model (factors which influence bioenergetic needs such as oxygen and nutrient consumption)
5. Behavioral model (role of psychosocial factors in preventing and treating disease)

These five models are commonly used in physical evaluation, diagnosis, treatment, and patient management. Their characteristics are summarized in Table 40.1.

40.1.2 The Somatic Dysfunction

The goal of the structural examination in osteopathic practice is the diagnosis of the somatic dysfunction in the body of the patient.

In the Glossary of Osteopathic Terminology, it is defined as "impaired or altered function of related components of the somatic (body framework) system: skeletal, arthrodial and myofascial structures, and their related vascular, lymphatic, and neural elements" (Educational Council on Osteopathic Principles of the American Association of Colleges of Osteopathic Medicine 2011).

Structural diagnosis uses the traditional physical diagnostic methods of observation, palpation, percussion, and auscultation. Of these, observation and palpation are the most useful.

Somatic dysfunctions are treatable using osteopathic manipulative treatment (OMT), which employs a variety of manual techniques with the scope of correcting or improving these dysfunctions.

It is named considering the major motion of the joint or tissue altered (i.e., restriction of elbow extension is named "flexion dysfunction").

Four criteria for the diagnosis of somatic dysfunctions are described:

1. Tenderness (a state of unusual sensitivity to touch or pressure)
2. Asymmetry (absence of symmetry of position or motion)
3. Range of motion changes (quality and/or quantity changes of joint or tissue mobility)
4. Tissue texture abnormality (a palpable change in tissues)

Table 40.1 Osteopathic five models (Chila 2011)

Model	Anatomical correlates	Health and physiologic function	Disease	Goals of osteopathic manipulative treatment (OMT)
Biomechanical	Postural muscles, spine, and extremities	Efficient and effective posture and motion throughout the musculoskeletal system	Somatic dysfunction, inefficient posture, joint motion restrictions or hypermobility, instability	Alleviate somatic dysfunction utilizing osteopathic palpatory diagnosis and OMT to restore normal motion and function throughout the body
Respiratory-circulatory	Thoracic inlet, thoracic and pelvic diaphragms, tentorium cerebelli, costal cage	Efficient and effective arterial supply, venous and lymphatic drainage to and from all cells, effective respiration	Vascular compromise, edema, tissue congestion, poor gas exchange	Remove mechanical impediments to respiration and circulation and relieve congestion and edema by improving venous and lymphatic drainage
Neurological	Head (organs of special senses), brain, spinal cord, autonomic nervous system, peripheral nerves	Efficient and effective cellular metabolic processes, energy expenditure and exchange, endocrine and immune regulation and control	Energy loss, fatigue, ineffective metabolic processes, toxic waste buildup, inflammation, infection, poor wound healing, poor nutrition, adverse response to medication, loss of endocrine control of vital functions	Restore efficient metabolic processes and bioenergetics, alleviate inflammation and infection, restore healing, and repair functions and endocrine control
Metabolic energy	Internal organs, endocrine glands	Efficient and effective sensory processing, neural integration and control, autonomic balance, central and peripheral nervous functions	Abnormal sensation, imbalance of autonomic functions, central and peripheral sensitization/malfunction, pain syndromes	Restore normal sensation, neurological processes, and control; alleviate pain
Behavioral	Brain	Efficient and effective mental, emotional, and spiritual functions, healthy lifestyle choices and activities, good social support system	Ineffective function due to drug abuse, environmental chemical exposure or trauma, poor lifestyle choices (i.e., inactivity, dietary indiscretions), inability to adapt to stress or environmental challenges	Assess and treat the whole person—physical, psychological, social, cultural, behavioral, and spiritual aspects; collaborative partnership; individualized patient care; and self-responsibility for healthy lifestyle choices

These diagnostic criteria may be remembered as the mnemonic TART (Educational Council on Osteopathic Principles of the American Association of Colleges of Osteopathic Medicine 2011; DiGiovanna et al. 2004; Chila 2011; DeStefano 2011) and are described in Table 40.2.

Somatic dysfunction plays a key role in the biomechanical and neurologic models and strongly influences the respiratory-circulatory, metabolic energy, and behavioral models.

Somatic dysfunctions may be identified in all body regions (head, cervical, thoracic, lumbar, sacral, pelvis, lower extremities, upper extremities, rib cage, abdomen) and are classified, referring to its severity, in mild, moderate, and severe (American Academy of Osteopathy 2005).

The diagnosis of somatic dysfunction can accompany many other diagnoses or can be present as an independent entity. The art of structural diagnosis is to define the presence of somatic dysfunction(s) and determine any significance to the patient's complaint or disease process presenting at the time.

The most common precipitating cause of somatic dysfunction is overuse injury from repetitive activities that strain and induce microtrauma in the soft tissues of the musculoskeletal system. Macrotrauma from injuries, inflammation from a variety of causes, and poor postural mechanics are other causes.

There are many concepts and theories about the pathophysiology of somatic dysfunction. There is no consensus about the complete mechanisms underlying the development, maintenance, resolution, and recurrence of the dysfunction, nor is there universal agreement about its importance to health and well-being, necessity of treatment, or effectiveness of manual therapies to resolve it. This lack of consensus among professionals and academicians across the globe makes this an exciting area for research (Seffinger and Hruby 2007).

Table 40.2 TART parameters (Educational Council on Osteopathic Principles of the American Association of Colleges of Osteopathic Medicine 2011; DiGiovanna et al. 2004; Chila 2011; DeStefano 2011)

T	Tenderness	Discomfort or pain elicited by the osteopathic practitioner through palpation. A state of unusual sensitivity to touch or pressure. Tenderness is particularly diagnostic if localized to a ligament. A normal ligament is not tender. A tender ligament is always abnormal
A	Asymmetry	Asymmetry of related parts of the musculoskeletal system either structural or functional. Examples might be the height of each shoulder by observation, height of iliac crest by palpation, and contour and function of the thoracic cage by observation and palpation. Asymmetry is usually discerned by observation and palpation
R	Range of motion (ROM) changes	Alteration in range of motion of a joint, several joints, or region of the musculoskeletal system is sought. The alteration may be either restricted or increased mobility. Restricted motion is the most common component of somatic dysfunction. ROM abnormality is determined by observation and palpation, using both active and passive patient cooperation. When ROM is restricted, it is said to meet an "abnormal barrier" to motion (Fig. 40.1)
T	Tissue texture abnormality (TTA)	A palpable change in tissues from skin to periarticular structures that represents any combination of the following signs, vasodilation, edema, flaccidity, hypertonicity, contracture, fibrosis, as well as the following symptoms: itching, pain, tenderness, paresthesias. Types of TTAs include bogginess, thickening, stringiness, ropiness, firmness (hardening), increased/decreased temperature, and increased/decreased moisture

40.1.3 Osteopathic Practice and Osteopathic Manipulative Treatment

An osteopathic consultation consists of the osteopath taking and recording a present and past case history and conducting appropriate osteopathic and clinical examinations to assist in the assessment of the patient.

The osteopathic practitioner formulates a working diagnosis and prognosis, communicates these effectively to patients and therefore plans an osteopathic treatment dealing appropriately with clinical findings, performs the treatment, and reassesses the results of this (European Federation of Osteopaths & Forum for Osteopathic Regulation in Europe 2012).

Osteopathic manipulative treatment (OMT) is the therapeutic application of manually guided forces by an osteopath to improve physiologic function and/or support homeostasis that has been altered by somatic dysfunction.

OMT employs a variety of techniques including articulatory, balanced ligamentous tension, cranial manipulations, strain and counterstrain, facilitated positional release, myofascial, high velocity/low amplitude, inhibitory pressures, visceral manipulations, muscle energy, soft tissue manipulations, and many others (Educational Council on Osteopathic Principles of the American Association of Colleges of Osteopathic Medicine 2011).

These manual techniques can be categorized as direct, indirect, combined, fluid, and reflex based.

Direct techniques may be applied specifically to a joint or nonspecifically to a body area. Direct techniques engage the restrictive barrier and use an activating force to correct the somatic dysfunction. Direct techniques may use thrust, impulse, muscle contraction, fascial loading, or passive range of motion to achieve the tissue response.

Indirect-, fluid-, balancing-, or reflex-based techniques may be applied specifically to a joint or nonspecifically to a body area. These techniques do not engage the restrictive barrier. These techniques may use fascial massage, fascial and soft tissue loading or unloading, hydraulic pressures, phases of respiration, and cranial or postural adjustments as part of the application of the technique (European Federation of Osteopaths & Forum for Osteopathic Regulation in Europe 2012).

OMT is used to influence patient's health in accordance with the aforementioned models.

40.2 Osteopathic Approach to the Elbow

Osteopathic clinical examination of the elbow includes the diagnosis of somatic dysfunction integrated into the examination procedure of the upper extremity and of the whole body. Even if the reason of consultation is a segmental problem, osteopathic clinician often performs the complete assessment of the patient. Observation of postural misalignment or asymmetries, for example, may indicate problems such as scoliosis, postural decompensation, anatomic short leg, or previous trauma or surgery and may affect the mobility of the upper extremity and elbow.

Osteopathic manipulative treatment directed at the somatic component of the patient's condition will improve the tissue's function and thus the patient's own ability to heal himself or herself (Chila 2011).

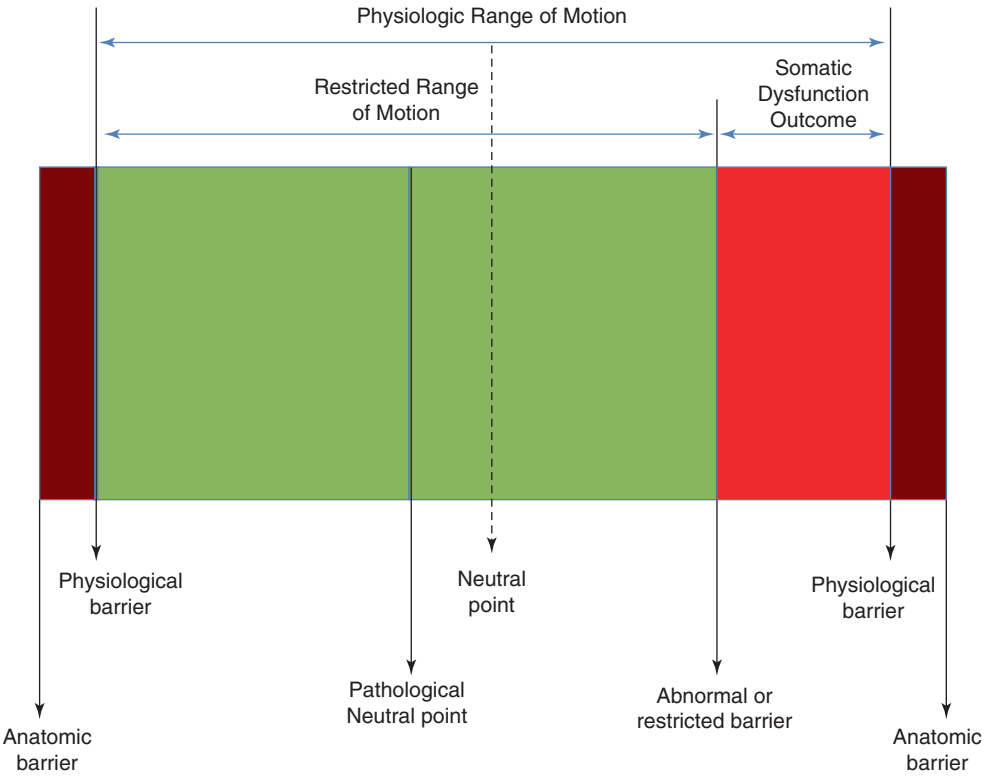


Fig. 40.1 Range of motion restriction in the somatic dysfunction

40.2.1 Assessment

Assessment of the elbow includes history, observation, palpation, and tests.

All the evaluations have the goal to highlight one or more TART parameters for the diagnosis of somatic dysfunction and to make differential diagnosis.

40.2.1.1 History

The clinician must determine the exact nature of the chief complaint, its duration, location, severity, and associated symptoms. The presenting complaint may be pain; however, it may also be weakness, swelling, or stiffness. The elbow is important in various arm movements, and restriction of motion may be the primary symptom. A history of trauma, acute or chronic, should be noted. Occupation, hobbies, sports activities, and activities of daily living should be evaluated.

40.2.1.2 Observation

The elbow should be examined first by observation. The carrying angle of the elbow should be noted, as should any swelling, which may be diffuse or localized to the olecranon bursa posteriorly. Signs of old or new trauma should be noted, such as scars, abrasions, bruises, and the like.

40.2.1.3 Palpation

The soft tissues and bony structures are then palpated to evaluate the integrity of the bones and the presence of any tenderness, masses, asymmetries, or crepitus. Any temperature changes should be noted, especially over the bursa and around the joints. Bony landmarks should be identified and compared between elbows. Swelling, especially over the olecranon bursa, should be noted. The olecranon bursa should not be palpable unless it is filled with fluid or thickened.

The ulnar nerve may be palpated in the groove between the medial epicondyle and the olecranon. The physician checks for scar tissue around the nerve that might compromise it.

40.2.1.4 Upper Extremity Mobility Test

The upper extremity mobility test (i.e., quick test—Fig. 40.2) screens for soft tissue or joint motion restrictions in the upper extremity. Proper function of the upper extremities requires good mobility of the sternoclavicular, acromioclavicular, glenohumeral, elbow, wrist, and hand joints, as well as properly functioning soft tissues and supportive structures:

- The patient stands facing the practitioner. This test can also be done seated on the examination table or on a stool.

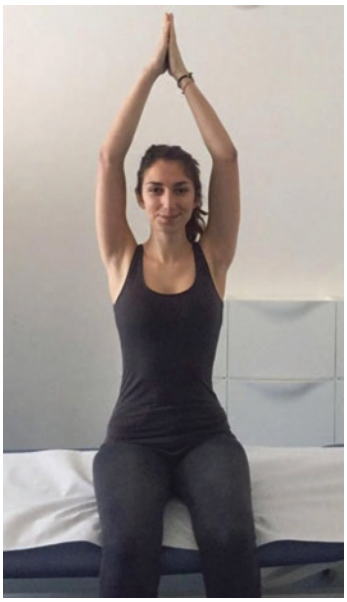


Fig. 40.2 Quick test for the upper extremity mobility

- The practitioner observes this motion from in front of the patient.
- The patient is instructed to raise (i.e., abduct) both arms in the coronal plane, as if reaching toward the ceiling, until the arms are fully overhead.
- The patient's arms should be able to almost touch the ears (i.e., 180 degrees of abduction), and the backs of the hands should be able to completely come together.
- Asymmetry or decreased range or quality of motion of the upper extremities signifies dysfunction of one or more of these joints and warrants further evaluation by regional and segmental evaluations (Seffinger and Hruby 2007).

40.2.1.5 Range of Motion Testing

Range of motion should be checked actively and passively. Extension is minimal because of bony impingement. Flexion will be limited by the size of the biceps muscle. Besides the gross motions of flexion, extension, supination, and pronation, the motion of the head of the radius must be evaluated as it glides on the lateral ulna. The motions of abduction and adduction of the ulna on the humerus should be evaluated.

40.2.1.6 Muscle Strength Testing

The muscle strength of each muscle group should be tested and, if found to be weak, the individual muscle strength should be evaluated. Muscle groups to be tested are flexors, extensors, pronators, and supinators.

Patients who repetitively use their forearms (manual therapists, carpenters, mechanics, etc.) may have increased tension and tenderness in the whole forearm muscular "system." This type of finding may be related to increased sympathetic tone from upper thoracic/rib somatic dysfunction, as well as overuse. However, repetitive overuse may strain the forearm, wrist, or elbow and can also very easily strain the forearm muscles and interosseous membrane; therefore, also this region has to be evaluated.

40.2.1.7 Neurologic Examination

The skin around the elbow and in the forearm may be tested for sensation. This is especially important with complaints of paresthesias or numbness.

When examining the elbow, it may be appropriate to test the deep tendon reflexes (brachioradialis, triceps, and biceps reflex) at the elbow and forearm. This is most commonly performed to rule out the compression/impingement of the nerves exiting from the foramina of the cervical spine.

40.2.1.8 Special Tests

- Tinel test: this is performed by tapping over the ulnar nerve as it passes between the olecranon and medial epicondyle. Marked sensitivity may be indicative of a neuroma or inflammation of the ulnar nerve.
- Tennis elbow test: this test is performed by stabilizing the forearm. Instruct the patient to make a fist and extend his wrist. Press against the dorsum of the patient's hand as he resists. When tennis elbow (lateral epicondylitis) is present, the patient will experience pain at the lateral epicondyle.
- Ligamentous stability: it may be necessary to test the elbow for ligamentous stability. This is performed by placing first a valgus stress and then a varus stress on the elbow, using one hand as a fulcrum and the other as an opposing force (DiGiovanna et al. 2004; Chila 2011).

40.2.1.9 Osteopathic Tests

- Osteopathic tests are performed with patient in supine or in sitting position. The osteopath is in front of her/him. The wrist under the osteopath's armpit sustains the patient's arm.
- To assess abduction/adduction of the ulna, the patient's elbow has to be positioned in extension, just before the anatomic barrier, and osteopath's hands sustain it. In the abduction test, the external hand pushes medially the joint to evaluate quality and amplitude of passive abduction motion of the ulna and vice versa for the adduction test (Fig. 40.3). Abduction is an accessory movement of pronation. Adduction is an accessory movement of supination.
- To assess rotations of the ulna, the patient's elbow has to be positioned in flexion, at about 90°; osteopath's fingers are around to humero-olecranon interlines for the palpation (Fig. 40.4). In the external rotation test, the elbow is passively flexed, and the osteopath evaluates the closure of



Fig. 40.3 Test for abduction/adduction of the ulna



Fig. 40.5 Test for anterior/posterior radial head glide

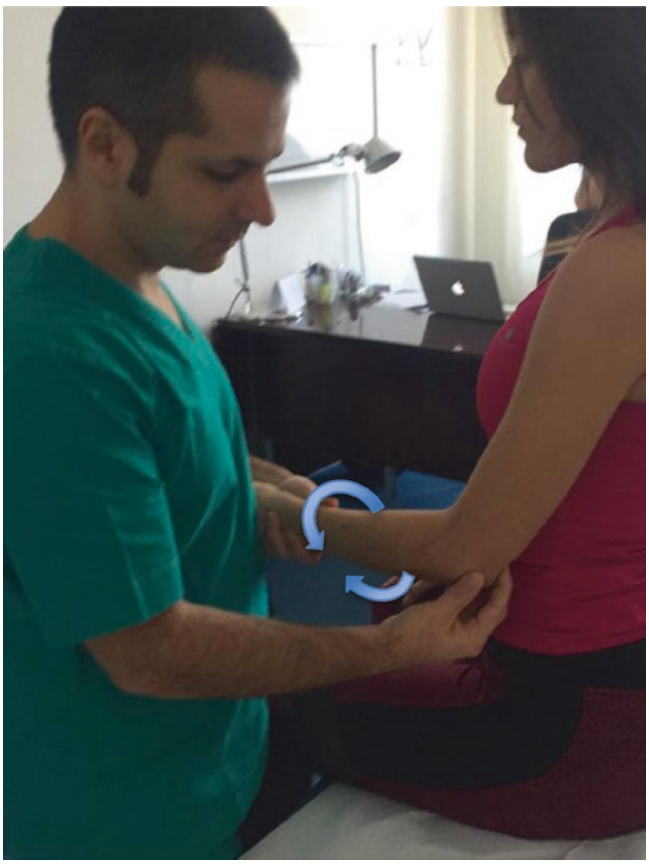


Fig. 40.4 Test for external/internal rotation of the ulna

Table 40.3 Radioulnar accessory movements during flexion/extension of the elbow

Elbow flexion (supination of the forearm facilitated)	Elbow extension (pronation of the forearm facilitated)
Abduction of the ulna	Adduction of the ulna
External rotation of the ulna	Internal rotation of the ulna
Anterior glide of the radial head	Posterior glide of the radial head

internal humero-olecranon interline and vice versa for the internal rotation test. External rotation is an accessory movement of supination. Internal rotation is an accessory movement of pronation (Gay 1996).

- To assess proximal radioulnar joint mobility, the osteopath's thumb and index of the external hand are placed forward and behind the radial head. The internal hand fixes the ulnohumeral joint at about 30°. Anterior radial head glide test is performed pushing it anteriorly and vice versa for the posterior radial head glide test (Fig. 40.5). Posterior glide of the radius is coupled with pronation/extension, and anterior glide is coupled with supination/flexion of the elbow.

Performing these tests, the practitioner has to mind all the humero-radioulnar movements of the elbow (Table 40.3).

40.2.2 Somatic Dysfunctions and Osteopathic Manipulative Treatment of the Elbow

Somatic dysfunctions can involve contraction of the related muscles, compression of the neural elements, strain of the ligamentous aspects, and restriction primarily of the accessory movements of the joint components.

The radial head typically entails posterior or anterior dysfunctions and may involve the muscles, the annular ligament, and the lateral collateral ligament. The humero-olecranon dysfunctions can involve the muscles and the medial collateral ligament and can be related to symptoms involving the ulnar nerve. Restriction of elbow extension (flexion dysfunction) and supination can involve the flexor muscles and compression of the median nerve. An extension dysfunction most likely will require treatment of the triceps component. Because of the overlapping of structures of the region, including the nerves, fascia, and especially the muscles that cross two joints, the search for the cause of dysfunction most frequently involves the adjacent regions of the shoulder and wrist/hand or other more distant regions of the body.

Somatic dysfunction of the elbow will affect full flexion and extension of the elbow. An elbow that does not go completely into extension typically has somatic dysfunction, an orthopedic condition, or both. The "smoothness" or quality of flexion and extension of the elbow may also be affected (Chila 2011).

In osteopathic medicine many dysfunctions are described for the elbow joint and its soft tissues. Here are presented the most frequent somatic dysfunctions with some examples of OMT techniques.

40.2.2.1 Ulnohumeral Abduction/Adduction Dysfunctions

They are usually due to falls with the elbow extended, and pain may be located around medial or lateral epicondyle. The forearm is limited in adduction or abduction.

High-velocity, low-amplitude thrusting technique:

- The patient is sitting; the practitioner is standing facing her/him. The technique may be performed also with patient in supine position.
- The practitioner grasps the patient's elbow. The fingers of his monitoring hand are on either side of the olecranon. The other hand is used to hold and stabilize the patient's forearm in supination/extension.
- The physician tests the motion of the radioulnar joint in abduction and adduction.
- If restriction of motion is noted in abduction, the physician places the patient's elbow into abduction and exerts a hyperabduction corrective thrust. This is performed with the elbow in extension, just before the anatomic barrier (Fig. 40.6).



Fig. 40.6 Technique to reduce a dysfunction in adduction of the ulna

- If restriction of motion is noted in adduction, the physician places the patient's elbow into adduction and exerts a hyper-adduction corrective thrust. This is performed with the elbow in extension, just before the anatomic barrier (DiGiovanna et al. 2004) (Fig. 40.7).

40.2.2.2 External Rotation Dysfunction of the Ulna

It is usually due to excessive supination movement or secondary to extension dysfunctions of the wrist. Pain may be present in the last degrees of motion of the elbow. External humero-olecranon interline is larger than the contralateral one.

High-velocity, low-amplitude thrusting technique:

- The patient is sitting; the practitioner is standing facing her/him. The technique may be performed also with patient in supine position.
- The practitioner's distal hand grasps the wrist. The patient's elbow is semi-flexed and the forearm is pronated. The proximal hand sustains the patient's elbow and pushes it medially, while the distal hand extends and increases the pronation at the end of extension, concluding the technique with an impulse toward pronation and extension of the elbow (Fig. 40.8).



Fig. 40.7 Technique to reduce a dysfunction in abduction of the ulna



Fig. 40.8 Technique to reduce a dysfunction in external rotation of the ulna

40.2.2.3 Internal Rotation Dysfunction of the Ulna

It is usually due to excessive pronation movement or secondary to flexion dysfunctions of the wrist. Pain may be present in the last degrees of motion of the elbow. Internal humero-olecranon interline is larger than the contralateral one.

High-velocity, low-amplitude thrusting technique:

- The patient is sitting; the practitioner is standing facing her/him. The technique may be performed also with patient in supine position.
- The practitioner's distal hand grasps the wrist. The patient's elbow is semi-flexed and the forearm is supinated. The proximal hand sustains the patient's elbow and pushes it laterally, while the distal hand increases the supination, concluding the technique with an impulse toward supination of the forearm (Fig. 40.9).

40.2.2.4 Radial Head Anterior Dysfunction

It is usually due to excessive pronation/supination or to a fall with elbow extended. It may be secondary to internal rotation dysfunction of the ulna.

High-velocity, low-amplitude thrusting technique:

- The patient is sitting; the practitioner is standing facing her/him. The technique may be performed also with patient in supine position.
- The practitioner grasps with the medial hand and the distal forearm and places the index and middle fingers of the lateral hand over the anterior aspect of the radial head. The operator pronates and flexes the patient's forearm, while the fingers hold the radial head posteriorly (Fig. 40.10). When the restrictive barrier is engaged, an increasing elbow flexion/pronation mobilization with impulse thrust is performed.

40.2.2.5 Radial Head Posterior Dysfunction

It is usually due to excessive pronation/supination or to a fall with elbow extended. It may be secondary to external rotation dysfunction of the ulna. It is also more common than the radial anterior dysfunction.

High-velocity, low-amplitude thrusting technique:

- The patient is sitting; the practitioner is standing facing her/him. The technique may be performed also with patient in supine position.

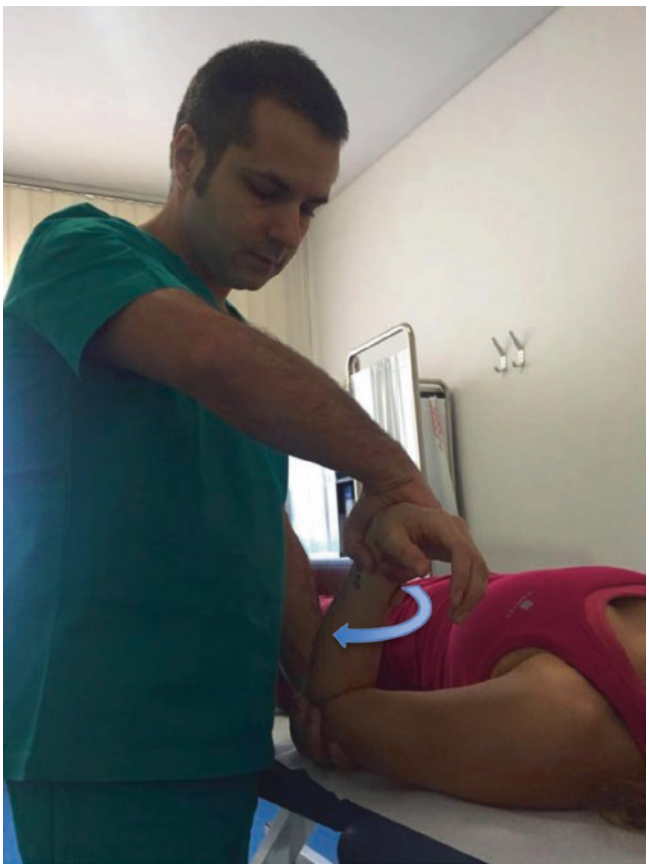


Fig. 40.9 Technique to reduce a dysfunction in internal rotation of the ulna

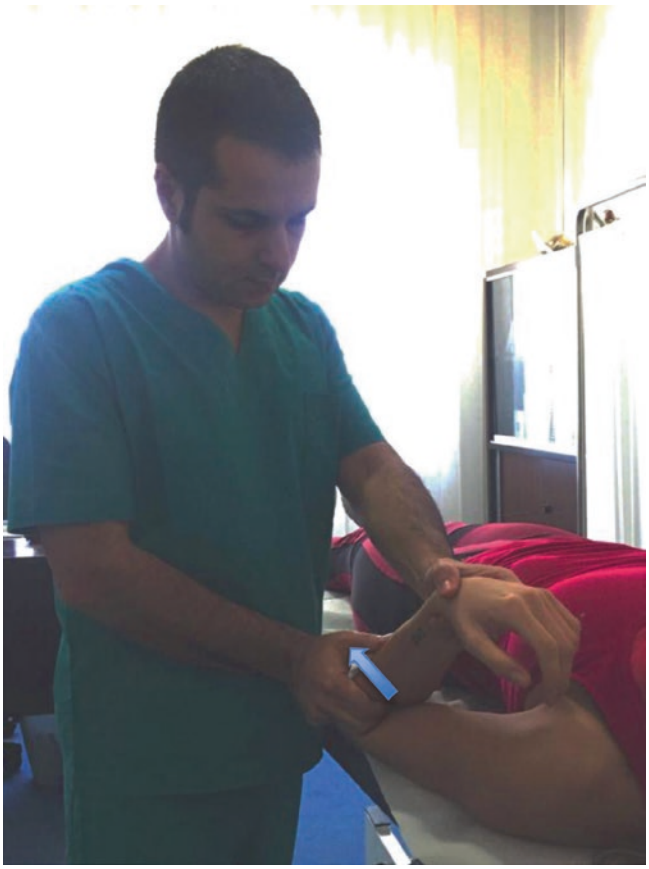


Fig. 40.10 Technique to reduce a radial head anterior dysfunction

- The practitioner grasps the proximal forearm with the index finger of the lateral hand overlying the posterior aspect of the radial head with the medial hand stabilizing the patient's ulnohumeral joint. He controls the patient's distal forearm, hand, and wrist between the elbow and the chest wall. The osteopath then engages a barrier of extension, supination, and slight adduction and performs mobilization with impulse thrust in a medial and anterior direction with the lateral hand (Fig. 40.11).

40.2.2.6 Elbow Flexion/Extension Dysfunction

These dysfunctions are secondary to abduction/adduction and/or rotation dysfunctions of the ulna and/or to radial head dysfunctions. Thus, elbow extension/flexion dysfunctions have to be treated after the normalization of other restrictions.

Muscle energy technique:

- The patient sits on the table with the operator standing in front. The technique may be performed also with patient in supine position.
- The operator's medial hand grasps the patient's distal forearm with the lateral hand stabilizing the elbow.
- Patient's elbow extension barrier is engaged.
- Patient performs a series of three to five muscle contractions toward flexion/supination for 3–5 s against the operator's resistance.
- Operator progressively engages elbow extension barrier after each muscle contraction (Fig. 40.12).
- Vice versa for the flexion restriction, in which the practitioner engages the restrictive flexion barrier (DeStefano 2011) (Fig. 40.13).

40.2.2.7 Pronation/Supination Dysfunction of the Forearm

Restricted pronation and supination of the forearm depends on motion of the humeroradial, proximal radioulnar, and distal radioulnar articulations. Thus, pronation/supination dysfunctions of the forearm have to be treated after the normalization of other restrictions. Supination is the most common dysfunction.

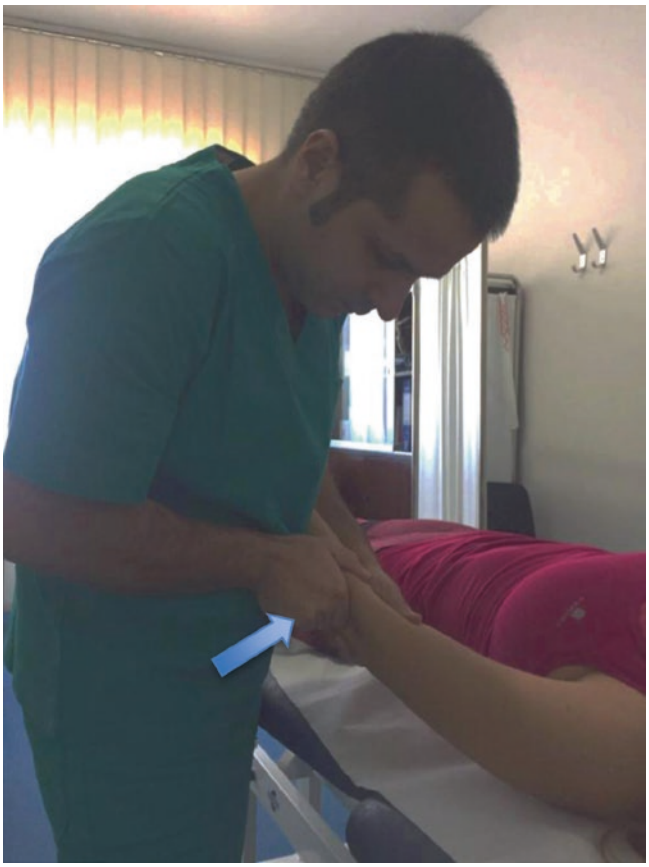


Fig. 40.11 Technique to reduce a radial head posterior dysfunction



Fig. 40.12 Technique to reduce a flexion dysfunction of the elbow

Muscle energy technique:

- The patient sits on the table with the operator standing in front. The technique may be performed also with patient in supine position.
- The operator's medial hand stabilizes the patient's elbow flexed to 90°. The lateral hand grasps the distal forearm, wrist, and hand with the patient's thumb pointing vertically.
- Operator introduces supination and pronation testing for restriction. Comparison is made with the opposite side.
- Treatment of restricted supination has the operator's lateral hand stabilizing the flexed elbow and monitoring the radial head, while the medial hand supinates the forearm to resistant barrier.
- Patient performs three to five muscle contractions for 3–5 s against resistance offered by the operator's medial hand.
- Operator engages a new supination barrier after each patient effort (Fig. 40.14).
- Vice versa for restricted pronation (DeStefano 2011) (Fig. 40.15).

40.2.2.8 Interosseous Membrane Dysfunction

The true elbow and wrist joints are functionally linked with the radius by the proximal and distal synovial radioulnar joints and a fibrous middle radioulnar joint called the interosseous membrane. The interosseous membrane maintains functional symmetry and stability of the forearm. The proximal and distal radioulnar joints allow pivot action, permitting supination and pronation of the hand. The fibers of the interosseous membrane extend cephalad from attachment on the ulna to a more proximal attachment on the radius. This arrangement allows the bones of the forearm to share the forces of compression whether they occur from the hand upward or the shoulder downward.

Interosseous membrane dysfunction can perpetuate elbow or wrist disability long after proper orthopedic care and complete healing of strains, sprains, or fractures of the elbow or wrist should have taken place. In some unknown way, the collagen tissues often retain stress patterns of past injury. This means that clinically, it is important to treat forearm dysfunction right away before these patterns have a chance to develop. In such cases, palpation of the interosseous membrane reveals increased tension and elicits areas of subjective



Fig. 40.13 Technique to reduce an extension dysfunction of the elbow

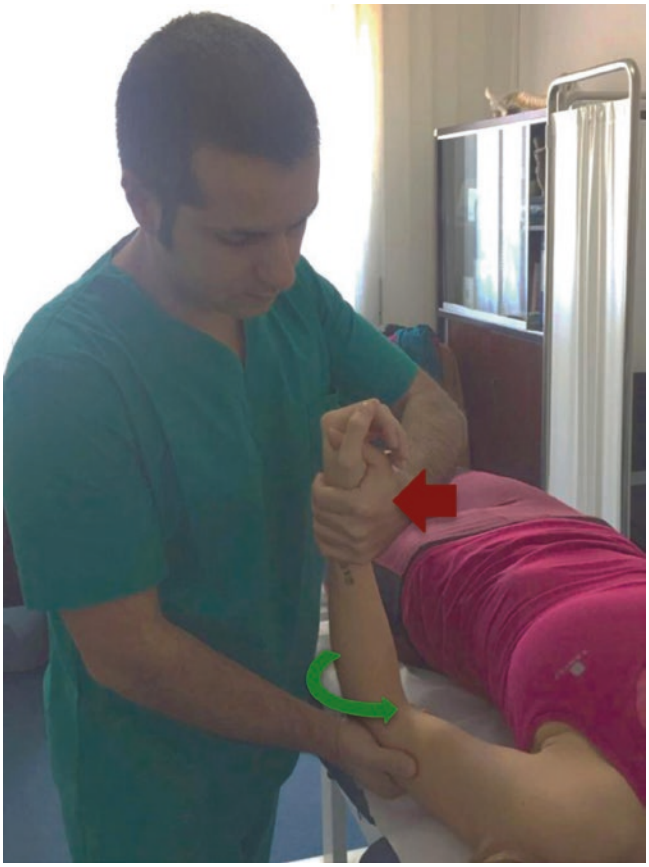


Fig. 40.14 Technique to reduce a pronation dysfunction of the elbow

tenderness. Interosseous strains may be treated with direct or indirect fascial treatments (Chila 2011).

Myofascial release technique:

- The patient is seated or supine. The practitioner stands in front and palpates the affected forearm over the interosseous membrane and notes any evidence of a taut, fibrous band, pain, or ease-bind tissue elasticity asymmetry.
- The practitioner places the thumbs over the anterior dysfunctional aspect of the interosseous membrane with the palm and fingers encircling the forearm.
- The practitioner monitors cephalad and caudad, left and right rotation, and clockwise and counterclockwise motion availability for ease-bind asymmetry (Fig. 40.16).
- After determining the presence of an ease-bind asymmetry, he will either indirectly or directly meet the ease-bind barrier, respectively. The force is applied in a very gentle to moderate manner and is held for 20–60 s or until a release is palpated (Nicholas and Nicholas 2011).

40.3 Osteopathic Manipulative Treatment of Lateral Epicondylitis

A typical condition that requires an osteopathic consultation is lateral epicondylitis (also called tennis elbow). This condition is thought to be an inflammatory response to overuse of the extensor muscle group attached to the lateral epicondyle of the humerus. There is also the thought that this condition may be related to a degenerative tendonosis and/or ischemic phenomenon. It is usually caused by repeated overload of the musculotendinous units. This condition produces pain that may be localized to the lateral epicondyle or may radiate down the forearm extensor group or up into the brachioradialis muscle. The pain is intensified by resistive extension of the wrist and fingers or by shaking hands. Pressure over the lateral epicondyle is painful.

Common areas of somatic dysfunction include the ipsilateral upper thoracic spine and ribs, the radial head

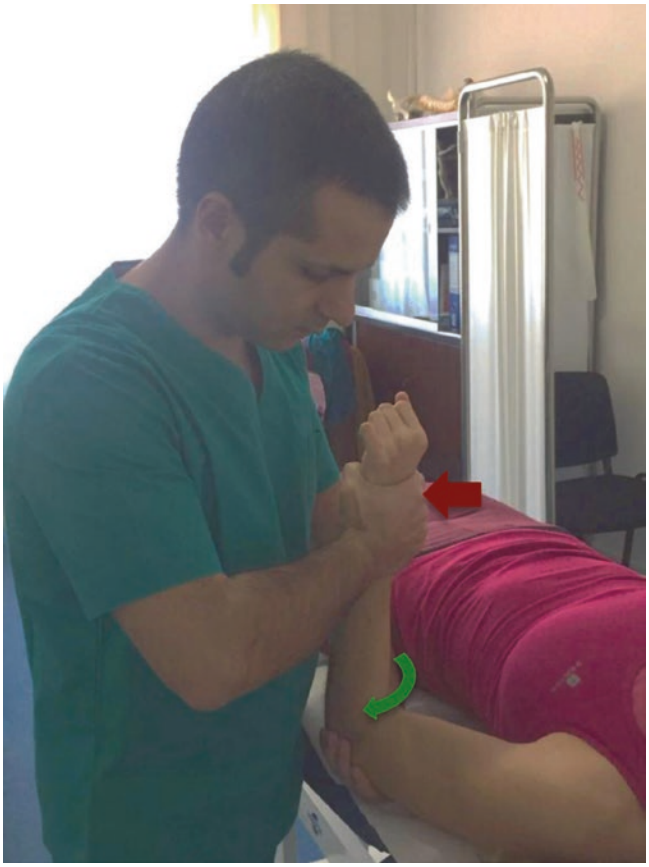


Fig. 40.15 Technique to reduce a supination dysfunction of the elbow



Fig. 40.16 Treatment for interosseous membrane dysfunction

and ulnohumeral joint, the lower cervical spine, and the pronator teres muscle. OMT directed to the upper thoracic spine and counterstrain for the affected ribs will decrease muscle tension of the forearm as well as tenderness of the lateral epicondyle. Counterstrain for the extensor tendons is useful as well. Treatment of a radial head dysfunction or an abducted ulna may completely resolve symptoms in patients with lateral epicondyle pain (Chila 2011).

Furthermore, a recent review concluded that myofascial pain and myofascial trigger points might be part of the lateral epicondylitis etiology. Treatment focusing on the myofascial component seems to be effective in reducing pain and improving function in patients with lateral epicondylitis. Additional trials are essential to attain a solid conclusion (Shmushkevich and Kalichman 2013).

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Pain Therapy and Acupuncture

41

Alessandro Ingardia, Laura Rossini, and Battista Borghi

41.1 Introduction

The elbow is a complex joint that enables forearm flexion/extension on the arm and forearm pronation/supination (Loeser 2003).

It consists of three smaller articulations:

- humeroulnar,
- humeroradial, and
- proximal radioulnar joint.

The elbow joint is stabilized by the articular capsule, which is attached superiorly to the humerus and inferiorly to the radius and ulna.

The capsule is reinforced anteriorly and posteriorly by a fibrous layer, whereas the external and internal collateral ligaments make up its lateral and medial portions.

Two muscle groups originate from the elbow:

- the epicondylar muscles, which allow finger and wrist extension, and
- the medial epicondylar muscles, which enable finger and wrist pronation and flexion.

Three muscles insert into the elbow joint:

- the biceps and the brachialis muscle, which enable forearm flexion and forearm supination on the arm, and
- the triceps muscle, which allows forearm extension on the arm.

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Inflammatory nociceptive pain involving the tendons of these muscle groups is the main indication for pain treatment, especially with intra-articular injection therapy.

However, since elbow pain is not due exclusively to mechanical causes, it is amenable to a multidisciplinary approach.

Mechanical pain is commonly localized to the joints. The pain radiating to the mid-arm, forearm, and hand compartment may be due to nerve compression (mixed or neuropathic pain).

The elbow joint receives motor and sensory innervation by nerves originating from the brachial plexus:

- musculocutaneous,
- median,
- ulnar, and
- radial nerve.

The dermatome map of the arm is shown in Fig. 41.1.

41.2 Causes of Elbow Pain

41.2.1 Nociceptive Pain

ACUTE

Extra-articular causes (the most common causes of elbow pain)

- Lateral epicondylitis (tennis elbow)
- Medial epicondylitis/epitrochleitis (golfer's elbow)
- Olecranon bursitis

Intra-articular disorders

- Arthritis (septic, autoimmune, and seronegative arthritis, osteomyelitis)
- Loose bodies
- Radial head fracture
- Osteochondritis dissecans

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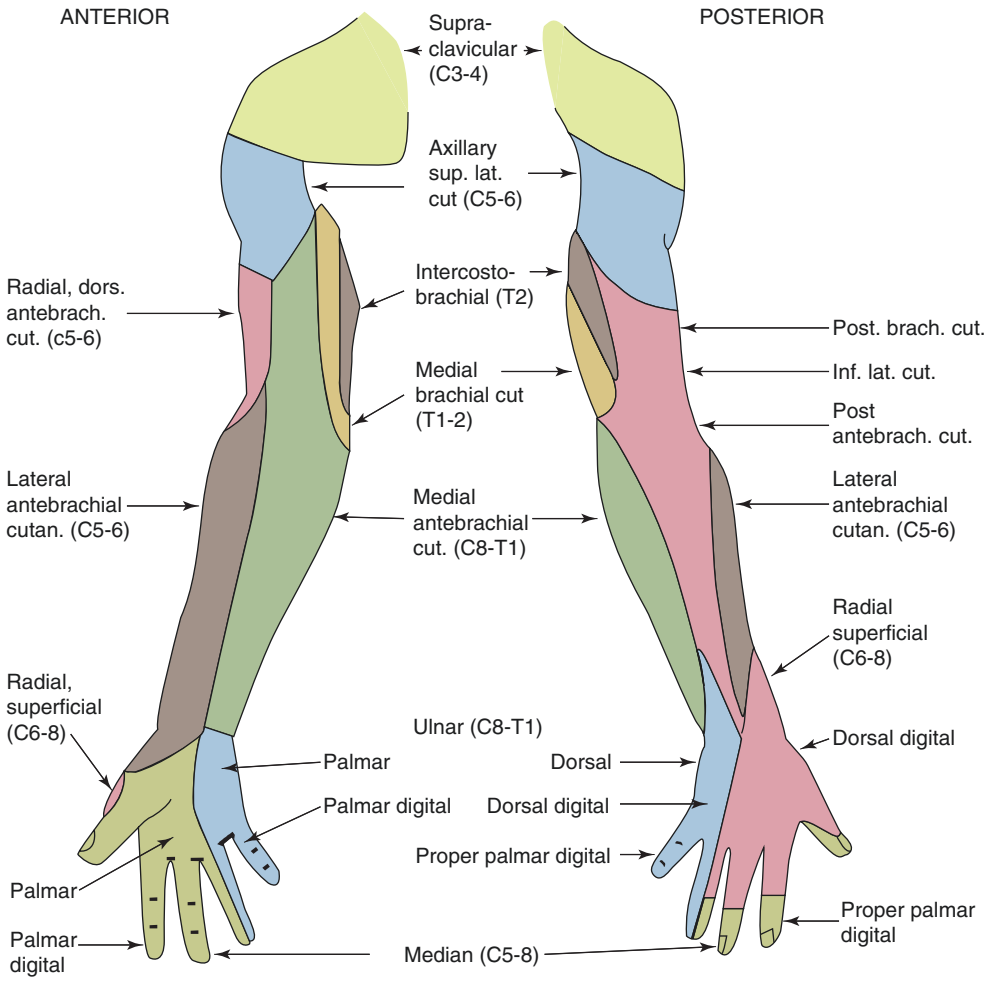


Fig. 41.1 Dermatome map of brachial plexus nerves

Postoperative pain

- Elbow arthroscopy
- Elbow arthrotomy

CHRONIC (degenerative arthropathies)

- Rheumatoid arthritis
- Primary arthritis (functional wear)
- Secondary arthritis (e.g. trauma, crystal deposits).

41.2.2 Neuropathic Pain

- Peripheral nerve injury (trauma, wounds, tumours)
- Entrapment syndromes:
  - median nerve compression at the elbow
  - anterior interosseous nerve compression
  - radial nerve compression at the elbow
  - ulnar nerve compression at the elbow: cubital tunnel syndrome; this is the second most common compression syndrome of a peripheral nerve after carpal tunnel syndrome; even though the ulnar nerve may be compressed at several sites along its course, the elbow accounts for the majority of cases.

41.2.3 Mixed Pain

- Cervicobrachial pain
- Complex Regional Pain Syndromes (CRPS) types I and II (formerly algodystrophic syndrome, reflex-sympathetic dystrophy syndrome, causalgia).

41.2.3.1 Cervicobrachial Pain

Cervicobrachial pain is notoriously resistant to traditional oral and systemic pain medications (Borghi et al. 2015). In these patients, blind or ultrasound-guided periradicular infiltration is more effective.

The drugs that can safely be administered by this route are substantially those used for intramuscular injections:

- NSAID
- corticosteroids
- local anaesthetics
- adjuvants.

41.2.3.2 Complex Regional Pain Syndromes (CRPS) Types I and II

CRPS are pathological entities where pain—the key symptom, either spontaneous or induced—is disproportionate to the event that has caused it. CRPS involve a number of variously combined autonomic and motor disturbances (International Association for The Study of Pain, IASP, 1994) (Bruehl et al. 1999).

They have been divided into:

- type I (formerly reflex-sympathetic dystrophy syndrome and similar disorders), involving trauma that does not entail nerve injury, and
- type II (formerly causalgia), involving lesion of a peripheral nerve.

A number of different causes contribute to CRPS development; some, like swelling, autoimmune response, abnormal cytokine production and release, sympathetic-sensory disorders, changes in local circulation, and central cortical causes (Borchers and Gershwin 2014; Harden 2012), are non-specific and lack a clear explanation.

41.3 Treatment

Multimodal treatment is currently considered as the gold standard for all types of pain, including elbow pain (Chou et al. 2016; Kehlet et al. 2002).

However, regional analgesia with local anaesthetics (or local anaesthetics combined with opioids) is more effective than systemic analgesia (i.e. opioids alone) in controlling postoperative pain and prevents the development of hyperalgesia and central sensitization (Wu 2011).

41.3.1 Drug Treatment

The treatment of elbow pain is based on its intensity (mild, moderate, severe), temporal profile (acute, chronic, persistent), and type (nociceptive, neuropathic). The safe pain medications used most often are as follows:

- paracetamol: mild, moderate, acute, and chronic pain
- NSAID/selective COX-2 inhibitors: mild, moderate, and acute pain (Jayanthi et al. 2016)
- tramadol: moderate, acute, and chronic pain (Lozada et al. 2015)
- tapentadol: moderate, severe, acute (not in Italy), and chronic pain (Hartrick et al. 2009)
- opioids: moderate, severe, acute, and chronic pain
- adjuvants (antiepileptics, tricyclic antidepressants/SSRI, dietary supplements): they help manage mixed pain in the framework of multimodal treatment by raising the pain threshold and stabilizing neuronal membranes
- bisphosphonates: besides being used for the treatment of osteoporosis, they have recently been promoted for use in osteoarthrosis (Spector 2003) and CRPS (Varenna et al. 2014; Varenna et al. 2013) according to precisely defined doses.

41.3.2 Invasive Pain Treatment

41.3.2.1 Single-Shot and Continuous Nerve Blocks (Wheeler et al. 2016; Tognù 2013; Fanelli 2007)

- supraclavicular brachial plexus block (Fig. 41.2)
- infraclavicular brachial plexus block
- axillary brachial plexus block.

According to the literature none is superior to the others (Frederiksen et al. 2010). The ultrasound-guided approach, though not required by any guideline, reduces the rate of adverse events (Fenten et al. 2015).

Indications:

- acute postoperative pain
- early postoperative pain
- joint release in patients with acute or chronic stiff elbow.



Fig. 41.2 Continuous supraclavicular brachial plexus block

41.3.2.2 Ultrasound-Guided Intra-Articular Injection

41.3.2.3 Peripheral Nerve Stimulation (PNS): NEUROMODULATION (Soloman et al. 2010)

Mechanism of action

Several hypotheses have been advanced to explain the pain relief provided by this approach:

1. a block of nociceptive afferents induced by peripheral electrical stimulation;
2. prolonged inhibition of spinothalamic neurons (gate control theory)(Chung et al. 1984).

Indications

1. neuropathic pain in the territory of a single nerve (ulnar, radial, median) after the failure of non-invasive treatments, in the absence of psychological contraindications and of positivity on screening tests
2. neuropathic pain in the territory of a single injured nerve (CRPS II)
3. effective nerve blockade does not ensure PNS success, whereas the ineffectiveness of a technically correct block often compromises it (Shetter et al. 1997).

Advantages

1. PNS does not involve peripheral or central nervous system injury and is better tolerated than neurotomy.
2. unlike spinal cord stimulation (SCS), PNS is highly selective and is not influenced by spinal movements.

Disadvantages

1. stimulation of a mixed nerve may induce secondary motor stimulation (rare)
2. perineural scarring may induce neurapraxia (rare)
3. implantation of the PNS electrode requires knowledge of the surgical technique, unlike the application of the percutaneous electrode in SCS.

Screening tests include:

1. preoperative percutaneous stimulation of the relevant nerve, to evaluate its territory and assess the motor response
2. when preoperative stimulation is not feasible, an electrode may be implanted provisionally, before implanting the device for chronic stimulation.

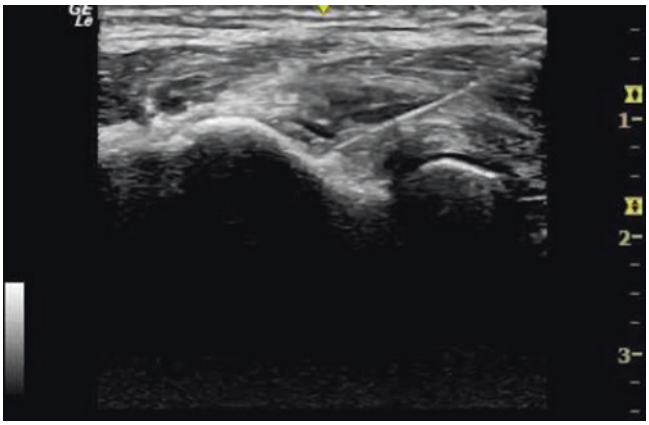


Fig. 41.3 Ultrasound-guided injection by Dr. ChiKai You© (torn radial collateral ligament)

41.3.2.4 Radiofrequency Neurotomy: DENERVATION

Unlike the neuromodulation approaches, which are reversible and reproducible, denervation involves irreversible nerve lesion and is definitive (Fig. 41.3).

41.3.3 Alternative Treatments

- Acupuncture (see paragraph 41.3.3.1)
- Physical therapy
- Physiokinesitherapy.

41.3.3.1 Acupuncture and Elbow Pain

Acupuncture, a mainstay of Traditional Chinese Medicine (TCM), has been used in China for 5000 years to treat a variety of conditions. TCM also includes phytotherapy, diet therapy, and medical gymnastics in a comprehensive medical system (see Chap. 42).

Acupuncture focuses on illness prevention rather than treatment, but is also used for a broad range of medical purposes that include pain relief as well as surgical anaesthesia.

Over the past few decades, acupuncture has gained wide recognition as a pain management approach. Support for its efficacy in several different conditions, like chronic low back pain, from evidence-based studies has led to its inclusion as a treatment option of clinical relevance in international recommendations such as those of the American Pain Society and the National Institute for Clinical Excellence (NICE Clinical Guidelines 2009; APS Guidelines 2007; Levis et al. 2010; Berman et al. 2010).

According to current evidence, acupuncture can be harnessed for the first-line treatment of migraine and tension

headache, as a complement to other non-pharmacological treatment options. It is at least as effective as prophylactic drug therapy (but has longer-lasting effects), it is safe, it appears to be cost-effective, and it allows reducing the intake of drugs that may have severe unwanted effects (Diener et al. 2006; Linde et al. 2009; Yang et al. 2011; Wang et al. 2011).

Other conditions where it has documented value include dysmenorrhoea, labour pain, knee osteoarthritis (Scharf et al. 2006), neck pain (Trinh et al. 2006; Vas et al. 2006; Trinh et al. 2007; Trinh et al. 2010), shoulder pain (Molsberger et al. 2010; Vas et al. 2008), elbow pain (Ahmad et al. 2013; Bisset et al. 2005; Fink et al. 2002; Green et al. 2002; Johnson et al. 2007; Salvi et al. 2011; Schleicher et al. 2010; Shiri and Viikari-Juntura 2011; Smidt and van der Windt 2006; Trinh et al. 2004; Trudel et al. 2004), and acute postoperative pain.

Of the 40 odd studies of elbow pain that have been published over the past 10 years, 14 (which include reviews, systematic reviews, and meta-analyses) have concluded that acupuncture is a useful treatment for epicondylitis (Ahmad et al. 2013; Shiri and Viikari-Juntura 2011; Schleicher et al. 2010; Bisset et al. 2005; Trinh et al. 2004; Trudel et al. 2004), while other investigations have called for additional high-quality studies to define its role (Green et al. 2002; Johnson et al. 2007; Salvi et al. 2011). In the review by Trinh et al. (2004), six high-quality (3–5 on the Jadad scale) randomised controlled studies involving heterogeneous treatment approaches (control group, sham acupuncture, outcomes) reported the efficacy of acupuncture in relieving short-term elbow pain. According to Fink et al. (2002), the beneficial effects of acupuncture continued for 1 year after the end of treatment (Ahmad et al. 2013; Bisset et al. 2005; Fink et al. 2002; Green et al. 2002; Johnson et al. 2007; Salvi et al. 2011; Schleicher et al. 2010; Shiri and Viikari-Juntura 2011; Smidt and van der Windt 2006; Trinh et al. 2004; Trudel et al. 2004).

Data demonstrating the effectiveness of acupuncture for conditions such as visceral pain syndromes, vascular ischaemic pain, phantom limb pain, and chronic postoperative and post-traumatic pain syndromes are less abundant, but they are continuously evolving as new, well-designed, high-quality studies with a suitable follow-up become available.

TCM is based on ancient knowledge, not on Western scientific empiricism. In this system, two opposing and complementary forces, Yin and Yang, coexist and interact with each other to regulate the flow of "vital energy", or Qi.

In a healthy individual Yin and Yang are in balance and the Qi is strong.

Qi is believed to circulate in the whole body through invisible channels called meridians or Jing Luo.

There are 12 major channels (six Yin and six Yang) and numerous minor channels that form a network of energy channels throughout the body.

Meridians do not correspond with anatomical structures, even though each is closely related to an internal organ or function. The main meridians include lung, heart, pericardium, kidney, spleen, liver, small intestine, large intestine, triple warmer, urinary bladder, stomach, and gallbladder. Their designation can be understood only in the context of TCM.

Along the meridians are more than 400 acupuncture points, each with its own function, which have also been classified by the World Health Organization. They are identified by name, number, and the meridian to which they belong. Other types of acupuncture points, which are located outside the meridians, are "extra" and Ashi points (Fig. 41.4).

The patient's pulse and tongue provide key diagnostic information on internal organs and functions.

Notably, TCM definitions and terms do not reflect Western physiological tenets, but are based on notions that have been formulated long before modern physiological knowledge became available.

TCM views the human body as a whole rather than a complex of symptoms. This is an important aspect that is sometimes lost in Western technical medicine—which tends to fragmentation—and is one of the reasons why TCM is gaining increasing popularity among patients and physicians.

There is currently a strong tendency to integrate the biopsychosocial model in modern pain management, which is what TCM does, since two individuals with the same disease may be treated in different ways, whereas different disorders may give rise to the same syndrome and be treated in a similar way.

The acupuncture points used for treatment are local, regional, and distant.



Fig. 41.4 Treatment of cervicobrachial pain with acupuncture

The mechanisms underpinning acupuncture-induced analgesia are still not completely clear. Modern physiological research has demonstrated that acupuncture exerts a neuromodulation effect on parts of the CNS and peripheral nervous system as well as on neurotransmitters.

Experimental work by Pomeranz (1987) has demonstrated that acupuncture stimulation activates A-δ and C afferent fibres in muscle, and that transmission of these stimuli to the spinal cord results in local release of dynorphin and enkephalins. These afferent pathways propagate to the midbrain and trigger a cascade of excitatory and inhibitory signals in the spinal cord, leading to release of serotonin, dopamine, and norepinephrine, suppression of pain transmission, and activation of the hypothalamus and pituitary gland with secretion of ACTH and endorphins.

Evidence from electroacupuncture (EA) studies indicates that low-frequency EA induces release of enkephalin and β-endorphins, whereas high-frequency EA leads to release of dynorphin. Moreover, EA at different frequencies has been reported to result in different gene expression in some CNS areas (Wang et al. 2008).

Over the past 10 years, studies employing advanced neuroimaging techniques, such as SPECT and functional MRI, have suggested that acupuncture stimulation and pain share similar central pathways involving the limbic system and adjacent structures (Wang et al. 2008). These areas also seem to participate in the modulation of the cognitive and affective dimensions of pain, and it has been proposed that the analgesic and anxiolytic effect of acupuncture, as well as other acupuncture-induced regulatory effects, may be mediated by the deactivation of these limbic, paralimbic, and neocortical circuits (Wang et al. 2008).

Further work is required to clarify the mechanism by which acupuncture exerts its analgesic effects.

Research into the anti-inflammatory effect of acupuncture has provided evidence suggesting the involvement of the hypothalamus–pituitary–adrenal axis, sympathetic pathways, and possibly parasympathetic cholinergic pathways.

Other important effects of acupuncture stimulation include antihistamine effects, down-regulation of proinflammatory cytokines (e.g. TNF-α, IL-1β, IL-6, and IL-10), proinflammatory neuropeptides, and neurotrophins, and suppression of COX-1, COX-2, and iNOS. Modulation of glutamate and aspartate receptors has also been implicated in the anti-inflammatory effect of acupuncture (Wang et al. 2008).

Pain specialists are trying to include acupuncture as a complementary technique in pain management together with manual therapy, physical exercises, psychotherapy, and pharmacotherapy within a therapeutic, rehabilitative, and preventive management framework.

Acupuncture may also offer a reasonable alternative to treat polypharmacy patients, like older patients, who are at risk of drug interactions, have contraindications to various drugs, or are intolerant to the side effects of their medications.

Cost is another major issue: the cost of acupuncture should be evaluated in relation to the savings accruing from a more limited/shorter use of drug therapy.

Although acupuncture is not completely risk-free, the risk is very low in expert hands.

It has been estimated that the incidence of major complications related to acupuncture treatment is 1:10,000–1,100,000(White et al. 1997).

Importantly, a survey of 574 acupuncturists and ca. 34,000 treatments has reported no serious adverse events, the most common events being nausea and fainting (1.3 per 1000 treatments)(MacPherson et al. 2001). According to another survey involving 10,000 treatments, there were 14 significant adverse events involving fainting, nausea, drowsiness, and anxiety, and 671 minor events involving puncture site bleeding and discomfort (White et al. 2001). Such low risk should be compared with the adverse effects of conventional treatments; for instance, NSAIDs are associated with considerable side effects that are dose-related and increase with rising age (Tramer et al. 2000).

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Physical Therapies and Shock Waves

42

Maria Cristina d'Agostino and Riccardo Turoni

42.1 Physical Therapies

Traditionally, for many decades, studies concerning the application of "physical" stimulations in the orthopedic and rehabilitation fields have been generally limited to the assessment of final general (positive or negative) outcomes of such therapies within a rehabilitation course, without thoroughly analyzing the possible actions, at biological level, that such "physical means" may produce on the treated tissues.

Only the scientific researches carried out in recent years have aimed at pointing out the effects of the physical stimulus (mechano-biological stimulus in case of merely mechanical stimulations) on the treated tissues and, most of all, at correlating the interactions of physical energies with different tissues and cell elements.

Among the pathologies most frequently affecting the elbow, a particular importance is given to the wide chapter concerning tendinopathies, followed by traumatic pathologies (possibly correlated fractures and bone consolidation disorders, i.e., pseudoarthrosis and consolidation delays).

With regard to elbow tendinopathies, according to the clinical experience, a high percentage of failures has been observed, both in conservative and surgical treatments; for this reason, it would be of paramount importance to opt for an attempt to treat tendon pathologies, whether in the acute or chronic phase, with a conservative approach. In the acute phase, an early treatment seems to have a positive impact on the long-term prognosis even if in the daily clinical practice, it may often be difficult to examine the patient in the first stages of the pathology onset. This is partly due to the patient's delay in consultation with the specialist (in the hope of spontaneous resolution) and partly to prior inadequate or partial treatments, which therefore result insufficient.

For both classes of the above pathologies (degenerative tendinopathies and post-traumatic diseases), the so-called "physical" therapies, together with the injection therapy, have represented the first-level therapeutic approach for decades, often on a mere empirical basis and without an international scientific validation. Only recently, and limited to some of these therapies, international scientific studies have been published; these studies seem to demonstrate their biological effects, thus justifying their application for therapeutic purposes. Among them it is worth mentioning low-intensity pulsed ultrasounds (LIPUS) and laser therapy (LT).

Additionally, among the physical stimulations having *in primis* a physical action, a specific chapter must be reserved to extracorporeal shock wave therapy (ESWT) (both focused or fESWT and radial or rSW), currently properly recognized as "mechanotherapy" and whose complex biological mechanisms of action (due to the well-known mechanotransduction mechanism) have been partially understood and described over recent years, still remaining in part under scientific investigation (Huang et al. 2013).

42.2 LIPUS

Ultrasounds (US) are a *physical therapy* used in clinical settings, based on the principle of high-frequency acoustic "vibrations" (higher than 20 kHz) that are produced by an electrical vibrating generator and having a tissue penetration potentially ranging from 2 to 5 cm (Fig. 42.1). The pressure variations generated in the tissues are essential to US therapeutic effects and depend on the application methods (immersion modality US therapy or by direct contact), on the application modality (pulsed or continuous), on the intensity

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Fig. 42.1 Example of LIPUS device (Osteotron IV)

(high or low), and on the duration of the session. Therefore, it is possible to obtain different effects: mechanical effects (cavitation and "micro massage"), thermal effects (an increase in the temperature of the treated tissue), and physical, chemical, and antalgic effects, associated with an increased microcirculation, a local chemical stimulation, and a possible disaggregation of cell connections in the structures involved. Absolute contraindications to US application are vascular pathologies (e.g., thrombophlebitis), acute sepsis, a radiotherapy cycle over the last 6 months, tumors, pregnancy, and cardiac diseases (in this case, patients shall be treated with low-intensity US). The possible risks due to an improper use of US are burns and periosteum overheating (Low and Reed n.d.; W.B. Saunders Company n.d.; Butterworth Heinemann n.d.; Edi Ermes srl n.d.-a, b).

Low-intensity pulsed ultrasounds (or LIPUS) are very low-intensity US (<0.1 W/cm^2); the studies carried out over the last 15 years have pointed out their effectiveness, especially in the treatment of ligament, tendon, and muscle pathologies, cartilage diseases (chondropathies), as well as fracture complications. In a literature review published in 2003, regarding the use of US in sport medicine, it was pointed out that LIPUS would be effective in 85% of pseudoarthrosis healing processes, with a significant reduction in healing time (Warden 2003; Massari et al. 2009). In addition, the combined use of LIPUS and pulsed electromagnetic fields has been proposed to positively interact in the bone tissue metabolism (osteogenesis activation) and to consider this technique as a potential conservative approach. The LIPUS therapy is carried out by means of a contact probe, a gel is applied between the probe and the anatomic part to be treated, and the therapy duration is 20 min per day (Romano et al. 2009).

Moreover, LIPUS is believed to be capable of stimulating bone regenerative processes during osteotendinous junction healing (Qin et al. 2006). If, on one hand, LIPUS do not seem to have a positive impact on painful symptomatology in case of tendinopathies (Warden et al. 2008), on the other one, it appears to be beneficial at the level of osteotendineous junction. In general, these animal experimental studies seem to encourage the application of LIPUS therapy, which can be considered as a valid biophysical therapeutic instrument in all pathological processes, where a bone damage is detected, especially at the tendon-bone junction level (Lu et al. 2008; Ying et al. 2012). Moreover, other "in vivo" animal studies seem to demonstrate that the combined use of LIPUS and functional electrostimulation can offer encouraging results in accelerating bone formation processes and favoring a greater elastic tension of tendon-bone junctions as well (Hu et al. 2014).

42.3 Laser Therapy

Light amplification by stimulated emission of radiation (LASER) therapy consists of a light amplification, via controlled emission of radiations; in other terms, the light produced, thanks to the electric stimulation of a specific element, is used for therapeutic purposes; this light is addressed to the body part to be treated for obtaining mechanical, thermal, or chemical effects.

According to the type of active material that, following electromagnetic excitement, produces the laser light, it is possible to distinguish between helium-neon (He-Ne) laser, CO_2 laser, excimer laser, diode laser, neodymium-doped yttrium aluminum garnet (Nd-Yag) laser, or argon laser.

The laser classification can be performed according to the specific power: Class I and Class II have a power lower than 1 mW (milliwatt) and are not suitable for medical rehabilitation purposes, Class IIIa includes the so-called low-level laser therapy (LLLT) having a low power (lower than 5 mW), Class IIIb includes high-power LLLT (lower than 500 mW), and finally Class IV includes very high-power surgical laser (higher than 500 mW) also called "hot lasers" (used, e.g., to cut metals).

According to the laser light emission mode, it is possible to distinguish among different equipment used for laser therapy: continuous emission equipment (capable of maintaining a high level of average power), pulsed emission equipment (the pulses emitted reach a greater peak power but at a low

average power), or very high-power super-pulsed emission equipment (power peak of 800 W and an average power of 4–5 W, for a greater tissue penetration capacity and a shorter duration of the therapy).

The numerous biological effects described after laser light stimulation are very interesting, especially if considering their possible applications in the therapeutic field:

1. Acceleration of tissue healing processes (due to activation of cell proliferation, increase in collagen and protein synthesis, wound revascularization, increase in collagen tension force, increase in ATP production, stimulation of macrophage, fibroblast, and lymphocyte activities)
2. Increase in local vascularization and microcirculation
3. Analgesic effect with reduced pain perception
4. Anti-inflammatory action

As a result, this therapy can be applied in post-traumatic pathologies (in case of edemas and scar formation processes), rheumatic pathologies (e.g., rheumatoid arthritis), dermatologic pathologies (ulcers, burns, acne), inflammatory pathologies concerning tendons and surrounding soft tissues, as well as all cases of arthralgia of inflammatory origin (based, e.g., on arthritic lesions).

The contraindications are pregnancy, neoplasms and epilepsy, infection or sepsis, areas of anesthesia in skin, and patients receiving immunosuppressive therapy. Moreover, while using a high-power laser, special attention should be addressed to areas of skin dysesthesia, patients with dark skin, wound suspect, or nevus important, and patients incapable of proper feedback verbal therapy (Benedicenti 2005; Fornezza 1986; D'Alessandro and Gialanella 2000; Cisari and Severini 1999; Gigante and Severini 1997; Baxter 1994).

From a general point of view, scientific studies and reviews carried out over the first 10 years of 2000 brought into question the effectiveness of "physical therapies" or some other conservative treatments (included SW, as we will see), like LLLT, acupuncture, orthotics, manipulations, or corticosteroid injections in the treatment of epicondylitis (Boisaubert et al. 2004; Bisset et al. 2005; Stasinopoulos and Johnson 2005; Lam and Cheing 2007; Johnson et al. 2007; Oken et al. 2008), reporting positive short-term therapeutic effects (pain relieving, improved gripping force and functionality) only in few cases, highlighting the lack of long-term effects, thus suggesting the so-called "wait and see" attitude and agreeing on the need of thorough, accurate studies with a high level of scientific reliability (Chesterton et al. 2011).

At the end of 2000, a study pointed out how the use of LLLT, associated with a program of eccentric exercises, stretching, and phototherapy, could give positive results (Stasinopoulos et al. 2009). Another study, published in the same year, seems to confirm the reliability of "tender point" or myofascial trigger point (MTrP) treatment by the use of LLLT (Chang et al. 2010).

Over the last few years, thanks to the technology evolution in the manufacturing of laser devices, in addition to the detailed study of dose-related biological effects, as well as the adoption of targeted protocols, according to the different pathologies, an increase in the number of scientific papers reporting the effectiveness of LLLT treatments has been observed. From the clinical point of view, its potential antalgic effect, with a consequent reduction of pain perception and disability degree, is reported; this therapeutic effect could be even greater in the treatment of epicondylitis by integrating different therapeutic methods, such as pulsed electromagnetic fields, LIPUS, manual techniques with the use of braces, and even ESWT (Bjordal et al. 2008; Emanet et al. 2010; Okuni et al. 2012; Dingemanse et al. 2014; Childress and Beutler 2013; Morimoto et al. 2013; Dundar et al. 2015).

The use of Class IV laser for chronic epicondylitis demonstrated a long-term effectiveness in hand gripping power, functionality, and pain reduction (Roberts et al. 2013). A study on chronic epicondylitis, comparing LLLT therapy and injections with platelet-rich plasma (PRP or platelet gel), seems to demonstrate that LLLT is more effective in the short-term, while PRP gives better results in the long-term follow-up (Tonk et al. 2014).

In the light of the increasing number of scientific studies documenting some biological effects and their therapeutic validity, it seems irrefutable that some so-called physical therapies may really represent a valid instrument for the healing process. However, it is essential that a correct diagnosis is followed by a personalized rehabilitative program, based on the correct integration of physiotherapy methods and medical practices within the framework of an integrated rehabilitation program, managed by a team of professionals; only in this way, it is possible to expect the highest level of health and patient recovery in the shortest time as possible.

42.3.1 Shock Waves

Originally introduced in medicine in the early 1990s for the treatment of renal stones (*lithotripsy*), extracorporeal shock wave therapy (ESWT) is now considered a valid tool in

a

1. Approved standard indications

1.1. Chronic Tendinopathies
- 1.1.1. Calcifying tendinopathy of the shoulder
- 1.1.2. Lateral epicondylopathy of the elbow (tennis elbow)
- 1.1.3. Greater trochanter pain syndrome
- 1.1.4. Patellar tendinopathy
- 1.1.5. Achilles tendinopathy
- 1.1.6. Plantar fasciitis, with or without heel spur

1.2. Bone Pathologies
- 1.2.1. Delayed bone healing
- 1.2.2. Bone Non-Union (pseudarthroses)
- 1.2.3. Stress fracture
- 1.2.4. Avascular bone necrosis without articular derangement
- 1.2.5. Osteochondritis Dissecans (OCD) without articular derangement

1.3. Skin Pathologies
- 1.3.1. Delayed or non-healing wounds
- 1.3.2. Skin ulcers
- 1.3.3. Non-circumferential burn wounds

2. Common empirically-tested clinical use

2.1. Tendinopathies
- 2.1.1. Rotator cuff tendinopathy without calcification
- 2.1.2. Medial epicondylopathy of the elbow
- 2.1.3. Adductor tendinopathy syndrome
- 2.1.4. Pes-Anserinus tendinopathy syndrome
- 2.1.5. Peroneal tendinopathy
- 2.1.6. Foot and ankle tendinopathies

2.2. Bone Pathologies
- 2.2.1. Bone marrow edema
- 2.2.2. Osgood Schlatter disease: Apophysitis of the anterior tibial tubercle
- 2.2.3. Tibial stress syndrome (shin splint)

2.3. Muscle Pathologies
- 2.3.1. Myofascial Syndrome
- 2.3.2. Muscle sprain without discontinuity

2.4. Skin Pathologies
- 2.4.1. Cellulite

3. Exceptional indications – expert indications

3.1. Musculoskeletal pathologies
- 3.1.1. Osteoarthritis
- 3.1.2. Dupuytren disease
- 3.1.3. Plantar fibromatosis (Ledderhose disease)
- 3.1.4. De Quervain disease
- 3.1.5. Trigger finger

3.2. Neurological pathologies
- 3.2.1. Spasticity
- 3.2.2. Polyneuropathy
- 3.2.3. Carpal Tunnel Syndrome

3.3. Urologic pathologies
- 3.3.1. Pelvic chronic pain syndrome (abacterial prostatitis)
- 3.3.2. Erectile dysfunction
- 3.3.3. Peyronie disease

3.4. Others
- 3.4.1. Lymphedema

4. Experimental Indications
- 4.1. Heart Muscle Ischemia
- 4.2. Peripheral nerve lesions
- 4.3. Pathologies of the spinal cord and brain
- 4.4. Skin calcinosis
- 4.5. Periodontal disease
- 4.6. Jawbone pathologies
- 4.7. Complex Regional Pain Syndrome (CRPS)
- 4.8. Osteoporosis

Fig. 42.2 ISMST Consensus Statement on ESWT Indications and Contraindications new *Consensus Statement* (Naples, October 2016)

b

CONTRAINDICATIONS

1. *Radial and focused waves with low energy*
   - 1.1. Malignant tumor in the treatment area (not as underlying disease)
   - 1.2. Fetus in the treatment area

2. *High energy focused waves*
   - 2.1. Lung tissue in the treatment area
   - 2.2. Malignant tumor in the treatment area (not as underlying disease)
   - 2.3. Epiphyseal plate in the treatment area
   - 2.4. Brain or Spine in the treatment area
   - 2.5. Severe coagulopathy
   - 2.6. Fetus in the treatment area

Fig. 42.2 (continued)

some other non-urological fields, especially orthopedics and rehabilitative medicine (mainly tendinopathies and some osseous pathologies) (Fig. 42.2). When applied on living tissues, in fact, ESWT does not produce a mechanical destructive effect (as for renal stone dissolution) but a pure biological action, whose best expression can be considered modulation and/or resolution of inflammation, aimed to tissue healing and regeneration (*mechanotransduction*) (d'Agostino et al. 2015; Wang 2012; Notarnicola and Moretti 2012; Romeo et al. 2014).

As non-invasive therapy, practically avoid of side effects and well tolerated by the patients (when applied according to the "rules" of good clinical practice), it can represent a strategic therapeutical tool, especially when some other therapies have failed, better if synergistically with some other therapeutical options (rehabilitation programs at first) (d'Agostino et al. 2015; Wang 2012; Notarnicola and Moretti 2012; Romeo et al. 2014).

The first scientific work regarding the possibility of stimulating bone healing in pseudoarthrosis was published in 1991 by Valchanou and Michailov. Since that time until today, ESWT quickly spread as *Orthotripsy* for the treatment of many musculoskeletal disorders, mainly tendinopathies. In spite of the clinical results and a growing body of scientific evidences, it was necessary to wait for several years, from first successful applications, to understand a great deal about the mechanisms of action of ESWT in the non-urological field (d'Agostino et al. 2015).

Shock waves (SWs) are acoustic waves, characterized by an initial positive very rapid phase of high amplitude, followed, after few microseconds, by a sudden phase of mild depression (negative pressure), before returning to the basic values (ambient pressure). Once produced from the "source," due to their morphology, they can propagate in any medium, with slightly different modalities (although water can be considered the best propagation medium). The physical characteristics of SW for the use in the therapeutic fields have been defined by a "consensus conference" in 1997, in

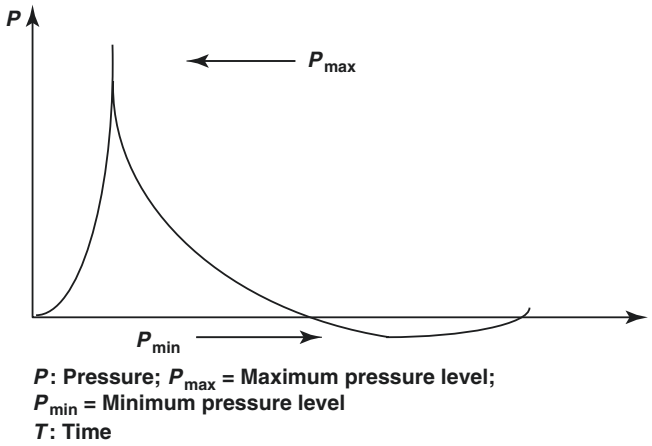


Fig. 42.3 Schematic description of a shock wave

relation to the parameters recognized by national and international scientific societies (d'Agostino et al. 2015; Gerdesmeyer et al. 2006) (Fig. 42.3):

- High peak pressure (100 MPa)
- Short term (<10 μs)
- Rapid rise in pressure (<10 ns)

There are currently three types of SW generators (*lithotripters*), according to the type of their sources: electrohydraulic, piezoelectric, and electromagnetic. In all cases, SWs are generated from a rapid increase in pressure (a sort of "micro-explosion") into the aqueous medium, and sooner, in order to exert their therapeutic action, they are "focused" (or directed) toward the "target" to be treated, as *focused* SW (fSW) (d'Agostino et al. 2015). According to the different SW sources and related clinical applications, some various lithotripters are produced, from the larger (generating high energy levels for bone treatments) to the more compact ones (mainly for soft tissue diseases and small bones). From the practical point of view, different types of generators will imply different treatment protocols (number of shots and corresponding energy levels) (d'Agostino et al. 2015).

Moreover, supported by scientific publications (basic science and clinical applications), since many years, also radial extracorporeal shock wave therapy (rESWT) is widely used in clinical practice. Radial waves (rSW) are acoustic waves, but, differently from fSW, they are generated with a *ballistic* mode: compressed air (or an electromagnetic field) is applied to fire a metallic bullet within a guiding tube that strikes a metal applicator placed on the patient's skin. This projectile generates stress waves in the applicator that transmit pressure waves (or rSW) noninvasively into tissues (Császár et al. 2015). They are not focused in depth and propagate in the tissue with a *radial* transmission, limited to the more superficial layers; nevertheless they can be used in the noninvasive treatment of various diseases of the musculoskeletal system and other soft tissue disorders (Gerdesmeyer et al. 2006; Császár et al. 2015).

Nowadays, it is scientifically evident that SWs, if correctly applied by an experienced and certified operator, with a proper device, on living tissues, although mechanical stimulations, do not exert a harmful or destructive effect (that is not a pure mechanical action), but really some biological effects on tissues and cells, whose functions and metabolism can be positively regulated. In other words, the mechanical stimuli can be considered only the "trigger," but not properly directly responsible of the ultimate effects of stimulation (d'Agostino et al. 2015; Notarnicola and Moretti 2012; Romeo et al. 2014; Wang 2003). The main mechanisms of action described so far for SW in non-urological fields are the following (d'Agostino et al. 2015; Notarnicola and Moretti 2012; Romeo et al. 2014):

- Changes in cellular membrane permeability
- Substance P dilution
- Small amyelinic nerve fiber reduction
- Nitric oxide production
- Growth factor production (VEGF, BMPs, OP, etc.)
- Proliferation, migration, and differentiation of stem cells

Very recently, it has been described a possible involvement of immune innate system following SW stimulation (in details, TL R3 receptor for *mechanotransduction* and macrophage activity in healing response, respectively), thus explaining a possible role of this therapy in improving self-healing abilities and connective tissue remodeling effects (Holfeld et al. 2014, 2016; Sukubo et al. 2015). From these basic mechanisms of action at the cellular and tissue level, some general important clinical results can be derived: analgesia, anti-inflammatory and anti-edema effects, angiogenesis, tissue regeneration, and remodeling (mainly skin and bone) (d'Agostino et al. 2015; Romeo et al. 2014).

In chronic tendinopathies, although the specific mechanisms by which SW can induce their therapeutic effects still remain partly unknown, some encouraging scientific results were recently obtained. Several authors, with in vitro and in vivo experiments, described a possible *trophic effect* of SW on tenocytes (positive regulation of cell vitality, collagen synthesis and anti-inflammatory cytokine release, expression of specific tendon markers) (d'Agostino et al. 2015). Moreover, by comparing the potential outcome of SW on human primary cultured tenocytes, derived from healthy versus other ruptured tendons, results would suggest that SW may supply faster post-injury recovery, thus explaining the available basic scientific evidences for using ESWT in tendon pathologies and suggesting a possible SW-induced mechanisms of tissue repair (Visco et al. 2014).



Fig. 42.4 Some types of lithotripters can be equipped with an in-line ultrasound (US) probe, in order to better target the anatomical region during shock wave treatment, when clinically requested

Moreover, in addition to tendinopathies and bone healing disturbances, nowadays, SW can be applied in some different fields of regenerative medicine, especially for the treatment of wounds and ulcers refractory to heal, as well as for painful scars of different origins, andrology, and cardiology (d'Agostino et al. 2015; Notarnicola and Moretti 2012; Romeo et al. 2014).

In daily clinical practice, SW treatments on "soft tissues" are applied on "outpatients," lasting up to 10–15 min; each cycle of ESWT usually consists of 3–4 sessions of treatment, at weekly interval. If properly applied, by experienced operator and with suitable equipment, it is a safe, almost painless, and relatively well-tolerated procedure. According to the international guidelines of the International Society for Medical Shockwave Treatment (ISMST), while for osseous application it is fundamental to target the pathological area through fluoroscopic control, for tendon applications, this is not so fundamental, but it may be of great utility to have diagnostic ultrasounds (US) as a control (SW *US coupled* or *US assisted*) while applying therapy, independently of calcifications (ISMST Consensus Conference, Juan Les Pins 2008, www.shockwavetherapy.org). According to some of the authors, ESWT would be consistently more effective with patient *feedback*, which enables directing SW to the most painful area (*clinical focusing*), rather than with anatomic or image-guided focusing (Sems et al. 2006). Moreover, US can help physician in monitoring recovery and follow-up of the tendon disease, in order to adapt and personalize the SW protocol to the modified clinical conditions, thus allowing best results and resource optimization (Fig. 42.4).

In conclusion, from a general point of view, ESWT, with its regenerative potential in non-urological fields, can be considered a true revolution in modern medicine: a pure mechanical stimulation can induce therapeutical biological reactions (so-called mechanotransduction), through growth factor production and stem cell stimulation, aimed at tissue repair and regeneration, thus involving new perspectives and insights also for the treatment of tendinopathies (d'Agostino et al. 2015; Notarnicola and Moretti 2012; Romeo et al. 2014).

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Brace and Rehabilitation

43

Alessandro Marinelli and Roberto Rotini

43.1 Introduction

Braces can be effective devices in different phases of elbow rehabilitation, and their use, especially if integrated with other modes of physical therapies, can improve the recovery in many elbow disorders. In clinical practice, elbow braces are generally preferred over casts, because they are more comfortable for the patients and more practical for the caregivers, allowing control of the swelling and skin conditions and to start an early and protected rehabilitation.

We can distinguish various categories of braces, articulated or non-articulated, custom molded, or prefabricated. The shapes and materials used to fabricate the elbow braces are very different and depend mostly on the specific function. On the basis of the function, we can identify two different types of braces: the protection braces and the mobilization braces. *The protection braces* are devices which prevent excessive stress on the articular surface and on the capsule, ligaments, or tendons; they are used after trauma and reconstructive surgeries, or in cases of inflammatory or degenerative situations, whereas the *mobilization braces*, used to treat elbow stiffness, are mechanical devices exerting forces to stretch the retracted tissue stimulating the recovery of the elbow movement.

Even if nowadays we have braces with improved design and materials with respect to the past, its use for the elbow joint is still more demanding—both for the doctors and for the patients—than in other joints, such as the knee, the wrist, or the shoulder.

It is important to consider that the elbow brace should not be thought of as an alternative to the physical therapist. On the contrary, the use of the elbow brace should be included in a global rehabilitation program shared between the orthopedic and the physical therapist.

The compliance of the patient with the brace program instructions is fundamental, and the patient must be carefully instructed on how to wear and use the brace.

The assistance of a skilled orthopedic technician can have a crucial role in the success of the rehabilitation program using an elbow brace. The technician has to build a custom-molded orthosis or adapt a brace available on the market that fits as well as possible on the patient's arm. The comfort of the brace is crucial for the tolerance and the compliance of the patient. The difficulties encountered most often are due to the different shapes and sizes of the arm and the fact that the braces can be heavy and cumbersome. Moreover, the presence of swelling modification during the treatment can often require the brace to be adapted or modified during the treatment.

Finally, in the first weeks after a surgical stiffness release, correct use of the elbow brace to prevent stiffness relapse can be performed only if there is correct pain management. Ice and analgesic drugs are important, but in some occasions the use of selective nerve blocks, performed by an anesthesiologist, is fundamental.

Therefore, the correct clinical indication, the compliance of the patient, the ability of the physical therapist in integrating the brace with other therapies (mobilization, massage, myofascial release, cryotherapy, etc.), the skill of the orthopedic technician in building or adapting the brace, and in some cases the correct pain management are all indispensable points to make the brace a powerful device in the elbow rehabilitation program.

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43.2 Elbow Brace Classification

We can identify two different types of brace with different functions: the protection braces and the mobilization braces (Table 43.1). Each type includes a great variety of braces, produced with different shapes and materials.

43.2.1 Protection Brace

The use of the protection brace is indicated after an acute trauma, after a surgery, or during the treatment of inflammatory or degenerative situations.

The role of the elbow brace is to protect the damaged structures of the joint, in some cases immobilizing or restricting the range of motion, permitting healing, and allowing an early but protected mobilization. The most common clinical situations are:

(a) The conservative treatment of an acute trauma, such as a simple elbow dislocation, collateral ligament lesion, or an un-displaced elbow fracture
(b) The conservative treatment of degenerative or inflammatory situations, like lateral epicondylitis or degenerative/rheumatic elbow disorders
(c) The postoperative care after bone fixation (distal humeral fractures, radial head fractures, olecranon fractures, coronoid process fractures) or after tendon repair (biceps or triceps), ligament reconstruction, or surgeries that might jeopardize the joint stability (e.g., radial head removal)

43.2.2 Mobilization Brace

The use of the mobilization brace is indicated in two clinical situations:

(a) The conservative treatment of posttraumatic elbow stiffness to exert a progressive distraction force with the aim of stretching the retracted capsular tissue and subsequently increasing the range of movement
(b) The postoperative course after a surgical arthrolysis, with the aim of avoiding the soft tissue contracture relapse and maintaining the range of motion achieved in the operating room

The protection braces are surely the most used and prescribed. Among the protection braces, we can recognize some different types.

1. *Non-articulated braces*: The purpose of these braces is purely to protect the elbow by completely restricting its movement. The non-articulated braces are made of rigid and usually light materials, moldable, and adjustable on the patient.

Table 43.1 Elbow brace classification

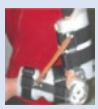
Elbow braces	Protection brace	Mobilization brace
Types of braces	-Non-articulated 	-Dynamic -Elastic or spring mechanism 
	-Sleeve  or forearm strap 	-Static progressive: -Turnbuckle type  -Gear hinge mechanism 
	-Articulated 	
Indications	-Acute trauma -After a surgery -Inflammatory/degenerative situations	-Conservative treatment of a posttraumatic elbow stiffness -Postoperative course after a surgical arthrolysis



Fig. 43.1 Sleeve braces with epicondyle pad



Fig. 43.2 Counterforce braces

The non-articulated braces are indicated in the initial phase after trauma or surgery, when an early movement cannot be allowed. For the patients, the braces are more comfortable than the heavy casts used in the past, but with respect to the arm-forearm-hand cylinder casts, they are less effective in controlling the prono-supination.

2. *Sleeve brace or forearm strap brace*: They present different shapes and usually are made with stretch elastic materials.

The sleeve braces are designed to manage the pain in many elbow disorders, like mild instability, minor trauma, arthritis (degenerative or inflammatory), olecranon bursitis, and lateral or medial epicondylitis. They are usually made of breathable stretching materials.

Some models present pads to place higher pressure on the lateral and/or medial epicondyle or to protect the olecranon from repetitive trauma (Fig. 43.1).

The forearm strap braces, also called counterforce braces, can be included in elbow braces, because they are prescribed for a specific elbow disorder: the lateral epicondylitis. These orthoses are designed to reduce the level of tension on the painful forearm tendons. They are wrapped around the forearm with a Velcro strap a couple of centimeters below the lateral epicondyle. Many models present foamed silicone pads to place pressure on the painful area (Fig. 43.2).

The rationale of the forearm strap brace is to produce compression at the level of the proximal extensor muscles to absorb stress, protecting the tendon-to-bone insertion. Moreover, the forearm strap brace can change the angle at which the tendon works, changing the direction of force, with the aim of relieving the symptoms of tennis elbow. In spite of the fact that they are commonly prescribed as one of the first treatments for lateral epicondylitis, the real efficacy is in doubt (Bisset et al. 2011). Sometimes, it is possible to observe, most of all in manual workers, that the use of the forearm strap brace can be associated with the appearance of more distal forearm pain, sometimes associated with symptoms of posterior interosseous nerve irritation. More rarely, the forearm strap braces can also be proposed for medial epicondylitis; in this case, it is important that the pressure is not directly applied to the ulnar nerve.

3. *Articulated*: The design of these braces has greatly improved in recent years. Many companies are now producing articulated braces that are lighter, easier to apply, and more comfortable with respect to the past. The movement is guaranteed by a hinge, with the possibility to set the ROM, usually allowed from 0 to 120° of flexion-extension, with increments of 10 or 15° (Fig. 43.3).

New braces allowing the respect of the physiological carrying angle and with possibility of flexion up to 140° are under study (Fig. 43.4).

A special handle to control the prono-supination, if required, can be attached to the articulated brace (Figs. 43.3 and 43.5). However, full control of the prono-supination is still difficult to achieve with a brace. A shoulder sling is usually furnished for greater patient comfort in supporting the upper limb (Fig. 43.5).

The articulated braces present a great versatility of use, according to the needs: they can protect the joint when the locking mechanism is fully locked; they can be adjusted



Fig. 43.3 Articulated elbow braces (X-Act ROM Elbow Donjoy DJO Global-Innovator X-Dr. Gibaud)



Fig. 43.4 Articulated elbow brace (Teus-FGP)



Fig. 43.5 Articulated elbow brace with handle and shoulder sling (Epico Revo – FGP)

to enable controlled movement when the system is partially locked; or they can help in maintaining the ROM obtained with the surgery or physical therapy if the locking mechanism is locked in full flexion or full extension. For this reason, some companies are studying systems to improve the lock in flexion of the hinge that is not possible with the current models over the 90° of flexion (Fig. 43.6).

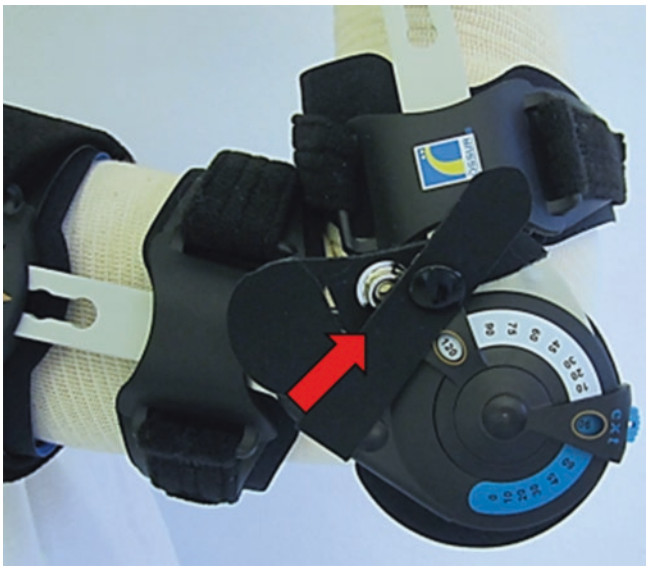


Fig. 43.6 Brace with string to maintain locked flexion at 120°

43.3 Mobilization Brace

The mobilization elbow braces are designed to exert distractive forces on the retracted soft tissues to increase the range of movement of the elbow after a traumatic elbow stiffness or a surgical release. Their rationale is that, by exerting a controlled stretching force on the soft tissues for a suitable time period, such tension is able to induce gradual and progressive lengthening of these tissues or prevent a stiffness relapse after surgical arthrolysis.

There are two types of mobilization elbow braces (Morrey 2009):

- Dynamic braces that work with an adjustable elastic or spring mechanism
- Static progressive brace that acts with distractive forces with a turnbuckle or a continuous gear hinge

Both types of braces (dynamic or static progressive) can be "custom made" or ready to use.

The mobilization braces exploit the viscous-elastic properties of the soft tissues, and their use, together with physical therapy, can induce a biological lengthening of the collagen fibers.

The main difference between dynamic and static progressive braces is the different force applied (Morrey 2009; Charalambous and Morrey 2012): the dynamic splinting uses the physical principle of the creep deformation by elastic or spring traction (low-load progressive stretch); the static progressive splinting uses the principle of the load relaxation by inelastic components: progressive hinges, turnbuckle, or gears to statically position the joint as close to end range as possible (load alternated to stress-relaxation).

While the dynamic brace produces a continuous stress on the soft tissues, inducing stretching, the static progressive brace, instead, produces alternating stress and rest phases: the soft tissues between two successive phases of progressive stretching, although remaining in tension, have the time to relax. Over time, a biological adaption of the tissue can be obtained.

The viscous-elastic characteristics of the soft tissues and the possibility therefore to be modeled substantially have been known since ancient times and are still exploited in some populations (Fig. 43.7). Such populations show us how, with stretching, a notable lengthening can be achieved through slow, gradual, and progressive phases of relaxation alternated with phases in which the tissues, despite remaining under stress, have time to adapt (Shewring et al. 1991; Sojbjerg 1996).

The rational principle of the method, therefore, is to obtain a small amount of gradual stretching to be maintained for long periods of time.

The static progressive mobilization braces present a micrometric regulation system managed by a knob or a turnbuckle to precisely adapt the tension applied and set minimal progressive adjustments (Fig. 43.8).

Even if the protective articulated brace can also be locked in a forced flexion or extension position to apply tension on the soft tissues, the fixed gap of 10–15° between one point of adjustment and the other (Figs. 43.3 and 43.6) makes these types of braces less functional in gaining motion than the progressive mobilization brace which, on the contrary, presents a continuous spectrum of regulations.

Independently from the mobilization brace used (dynamic or static progressive, turnbuckle or with a gear hinge, custom made or prefabricated), these types of braces show their limits mostly in the last degrees of flexion-extension. Therefore, it is usually necessary to incorporate physical therapy to recover the extreme degrees of movement.

In particular, the progressive static turnbuckle-type braces, mostly at the last degree of flexion, produce compression forces and, at the last degree of extension, distraction forces on the ulno-humeral joint (Morrey 2009).

The knob-type brace, in which the force is directly applied to the axis of rotation, does not produce compression or distraction forces and is usually better managed by the patients. However, frequent malposition, skin hyperpressure, and difficulties in reaching the last degrees of movement are also common problems with knob-type braces.

In the literature, there is no definitive data to support the use of dynamic (Shewring et al. 1991; Sojbjerg 1996; Gallucci et al. 2014) or static progressive mobilization braces



Fig. 43.7 Ancient art of lengthening the soft tissues, using slow and progressive stretching technique

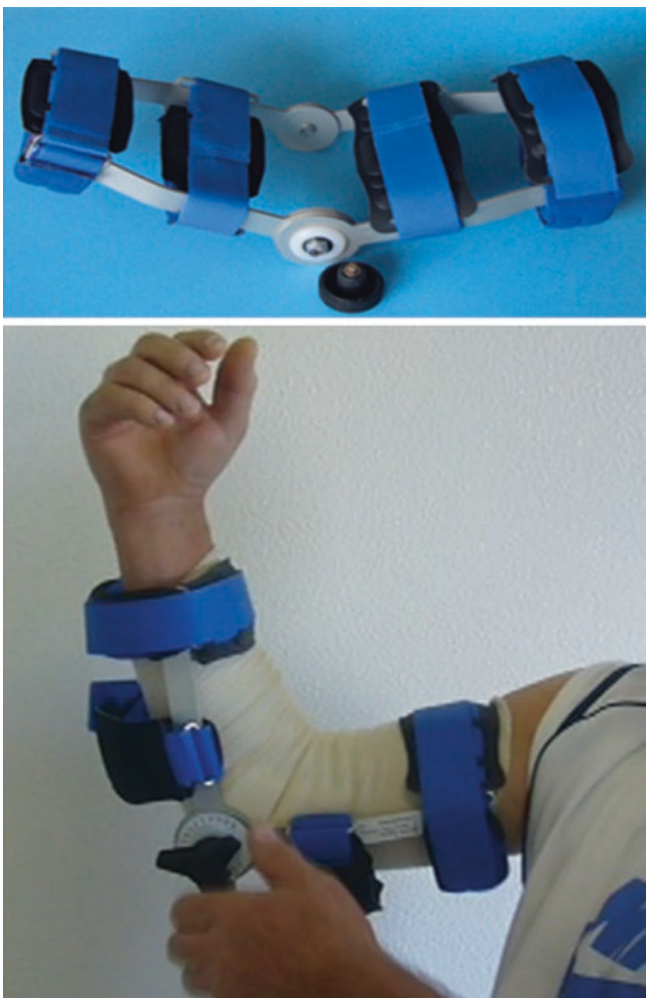


Fig. 43.8 Static progressive mobilization brace-knob type (MTO-Spa)

(Bonutti et al. 1994; Gelinas et al. 2000; Doornberg et al. 2006; Marinelli et al. 2010).

There is a randomized controlled trial (Lindenhovius et al. 2012) and two systematic reviews (Müller et al. 2013; Veltman et al. 2015) reporting good results in the treatment of elbow stiffness with both braces, without significant differences. However, most of the authors prefer the use of a static progressive brace that can be adjusted incrementally by the patient, setting the appropriate tension and minimizing the risk of overstretching and damaging the tissues. Regarding the use of the dynamic splinting, there is concern that the elastic tension is not readily or precisely adjustable and that continuous force applied to soft tissues can exceed their elastic capacity, causing inflammation and discomfort and leading patients to interrupt its use.

Mobilization braces for pronation-supination stiffness have received less attention until now, but the recovery of the forearm rotation is as important as the movement in flexion-extension and equally difficult to recover.

There are mobilization braces that can exert distraction in flexion-extension, and if needed, a rotational device can be applied distally to the brace to stretch the tissues also in prono-supination (Fig. 43.9).

If the stretching in prono-supination is the only one required, it is possible to use a custom-made thermoplastic brace that can exert specifically prono-supination forces (Fig. 43.10). The brace we commonly use is made up of two parts: the proximal portion is angled at 90° and conforms to the elbow and the distal portion is straight and conforms to the wrist and the hand, leaving the interphalangeal joints free to move; the two parts overlap at the forearm level and one can slide over the other.

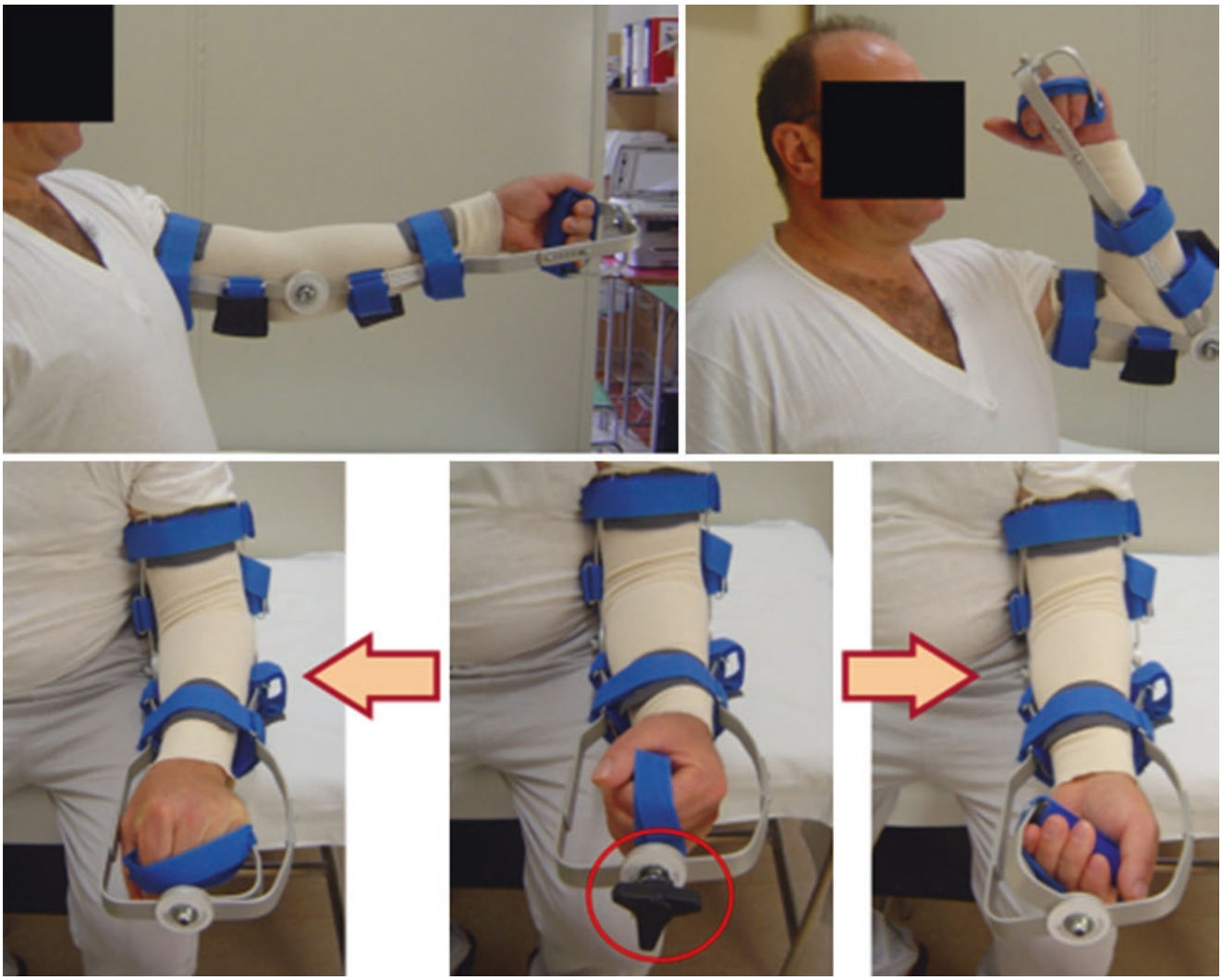


Fig. 43.9 Static progressive mobilization brace to exert flexion-extension and prono-supination stretching forces: MTO

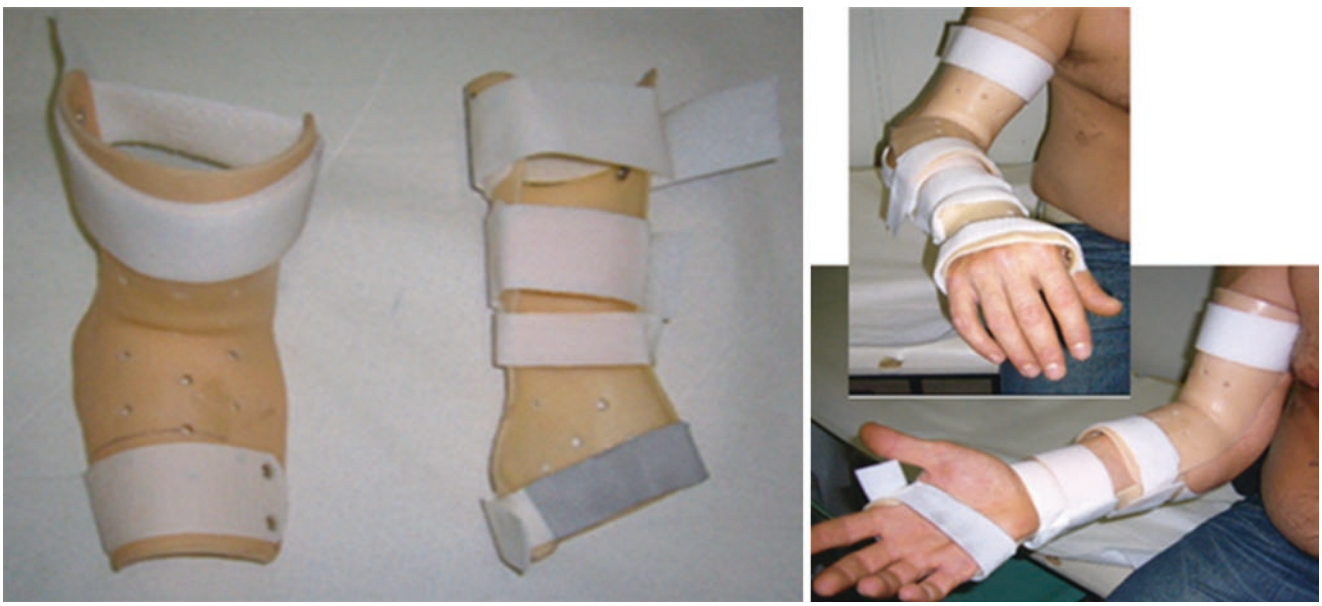


Fig. 43.10 Thermoplastic brace for forearm rotation stretching

Pronation-supination forces are applied by rotating the distal part on the first one, and the position reached is fixed using Velcro straps. Different brace models for the restoration of rotational motion of the forearm are presented by other authors (Shah et al. 2002; Lee et al. 2003; McGrath et al. 2009). Although this brace offers the advantage of allowing gradual recovery of pronation-supination, independently of the model used, they present several disadvantages: they are bulky, difficult to put on, impractical for carrying out even an easy routine task, and uncomfortable for use at night.

43.4 Elbow Brace: Indications and Protocols

We can identify four main situations where the brace can have a specific indication in elbow rehabilitation. In the first two cases, the protective braces are used and in the final two the mobilization braces.

43.4.1 Acute Trauma

The elbow brace, after fracture or dislocation, can have both protective and rehabilitation purposes, allowing the stress forces and the dangerous movements to be limited to permit the bone and the soft tissues to heal correctly, allowing early but protected movement within an allowed range of motion.

The protective articulated brace (Figs. 43.3 and 43.5) is therefore the most used in these situations.

After a simple elbow dislocation, for example, a protective articulated brace is kept locked at 90° of flexion-extension for the first 5–15 days depending on the severity of the damaged structures. The aim of the brace is to prevent dangerous degrees of movement, to avoid the dangerous varus stress on the lateral collateral ligament produced by the shoulder abduction and to permit early passive and active movement in the allowed range of motion.

The protection articulated brace can also be indicated for the conservative treatment of radial head or coronoid fractures. Based on the healing of the damaged elbow stabilizers, the range of motion can be progressively improved and the patient, wearing the brace, can start performing many everyday tasks. The use of the brace is usually discontinued at rest after 3–6 weeks, and during weight lifting after 4–8 weeks, to be evaluated case by case.

43.4.2 Postoperative Course After Fracture Fixation or Ligament/Tendon Repair or Reconstruction

In the first period after distal humerus, olecranon, or radial head fracture fixation and after an elbow or radial head replacement or ligament/tendon reconstruction or repair, elbow immobilization is useful; in a second phase, an articulated protection brace is generally used.

The brace protocol and the physical therapy have to be personalized according to the fixation strength, ligament stability, pain, and risk of stiffness.

43.4.3 Conservative Treatment of Elbow Stiffness by Brace

The idea of treating elbow stiffness with devices that allow progressive distraction of soft tissues goes back centuries, as testified by a woodcut dated 1517 showing a static progressive splint very similar to the modern turnbuckle braces currently used (Rotini and Marinelli 2008) (Fig. 43.11).

Before considering the brace as treatment for elbow stiffness, we have to assess the type of stiffness (intrinsic or extrinsic), the type of end point of motion (rigid or springy), the degree of stiffness (mild, moderate, severe, and very severe), the duration of stiffness, and some of the patient's characteristics such as age, expectations, and motivations.

The indications and contraindications for treatment of elbow stiffness with a brace are summarized in Table 43.2.

At present there is a lack of consensus among the authors about how many hours a day the brace should be used, and the bracing protocol varies from three sessions a day for 30 min for a period to 1–4 months (Lindenhovius et al. 2012) to 15 h a day for an average of 5 months (Gelinas et al. 2000).

In the clinical practice, it is also important to consider the initial degree of contracture, the splint tolerance, the personal circumstances, the compliance, the rate of progression, and the possibility of integrating the brace with other modalities of rehabilitation treatment.

For the use of the brace, it is generally agreed that if the tension applied is insufficient, the stretching action will be ineffective; if however it is excessive or the stretching action

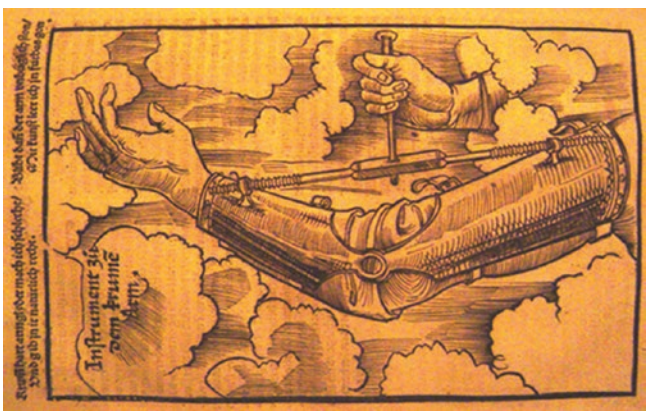


Fig. 43.11 Woodcut 1517. Von gersorf H: Feldbuch der Wundarznei, Strassburg. Consultable at Putti Donation, Istituto Ortopedico Rizzoli, Bologna-Italy

Table 43.2 Indications and contraindications for bracing in elbow stiffness

Indications	Contra-indications
Extrinsic stiffness	Intrinsic stiffness
Moderate grade (ROM between 60° and 90°)	Severe stiffness (ROM between 30° and 60°) or very severe (ROM <30°)
Springy end point of motion	Presence of significant heterotopic ossifications
Onset not longer than 6–8 months before treatment	Onset longer than 6 months for an adult, 1 year for a child
Patient highly motivated	Poor patient compliance or impossibility to follow the patient
Good skin condition	Poor skin condition
No ulnar nerve neuropathy	Ulnar nerve neuropathy

is performed too quickly, the tissues will be damaged, resulting in antalgic contracture, bleeding, an increase in scarring, heterotopic ossifications, and worsening of the stiffness. It is therefore fundamental to inform the patient that when the brace is worn, a tolerable level of tension and mild to moderate stretching sensation should be felt.

A shared rule is that in the treatment of any contracture, the brace should be applied in both directions (flexion-extension) to ensure that motion gained in one direction is not lost in the other.

Our preference of bracing protocol is to prescribe the brace at least for 4–6 h during the day, with at least four sessions a day 1 h each and combining the time of the brace with those for the physical therapy (massage, gentle manipulation, hydrokinesitherapy). During the night we always suggest wearing the splint in the extension position, because in our experience the flexion position does not allow the majority of the patients to sleep.

Most improvement is noted in the first weeks of treatment. The use of the brace is usually discontinued after 3–6 months, when there is no further improvement in the range of motion for a period of 1 month.

The bracing program is suspended gradually, checking that the range of movement achieved is not going to decrease and encouraging the patient to keep performing range-of-motion exercises to maintain the improvements.

With correct indications, our experience shows that the mobilization elbow brace is a useful device, perhaps sometimes unjustly underappreciated and underutilized (Marinelli et al. 2010).

The few studies present in the literature confirm the good results obtainable with the mobilization brace, reporting a total improvement in the flexion-extension ranging from 20° to 40° (Bonutti et al. 1994; Gelinas et al. 2000; Doornberg et al. 2006; Marinelli et al. 2010; Green and McCoy 1979; Ulrich et al. 2010) with a low rate of complications: heterotopic ossification 10%, ulnar nerve neuropathy 7% (only 50% of them required a surgical nerve decompression), and no improvement 7% (Veltman et al. 2015).

43.4.4 Mobilization Brace After Soft Tissue Release

One of the greatest difficulties after surgical release in the treatment of stiff elbow is to maintain the range of movement obtained in the operating room in the following postoperative phase. In fact, after soft tissue release, the elbow stiffness has the tendency to recur in four phases: bleeding, edema, granulation tissue, and fibrosis. Such phases develop within hours, days, weeks, and months, respectively (Fig. 43.12).

To decrease the bleeding and edema phases, it is possible to set the limb extended and unloaded, to use a compressive bandage, and to prescribe NSAIDs and continuous passive mobilization. Compression ice systems, with gentle squeezing to augment venous and lymphatic return, can be useful in this phase (Fig. 43.13).

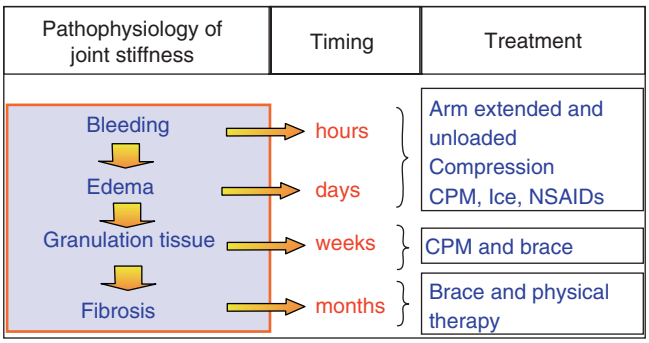


Fig. 43.12 Pathophysiology of soft tissue contraction and its treatment



Fig. 43.13 Device for cryotherapy, compression, and magnetotherapy (Cryo Mag-Simed srl)



Fig. 43.14 Elbow CPM machine, Kinetec 6080, Smith and Nephew

Continuous passive movement (CPM) (Fig. 43.14), together with the brace, is also used during the following granulation phase, with the aim of reducing swelling and preventing the formation of scar tissue.

It is useful to underline that CPM is useful in the prevention and reduction of swelling and maintains the movement already present (e.g., obtained with a surgical release), but by itself does not induce its increase; squeezing the soft tissue at the end of the flexion and extension movement reduces the soft tissue elbow swelling and helps to maintain the full range of motion (O'Driscoll and Giori 2000).

To increase the movement through the stretching of the retracted soft tissue, the only tools are mobilization braces or joint manipulation. Braces and physical therapy are in fact specifically indicated in the last phase, where the fibrosis formation occurs with the following natural tendency of the soft tissue to shorten and retract.

In our experience, the mobilization braces are useful devices especially in more severe stiffness cases after having obtained with surgical arthrolysis more than 50–60° of improvement in ROM. The protocol we use consists in alternating the extension and flexion position every 60 min 3–4 times a day and using CPM machine 2–3 times a day for 20–30 min in the time free from the brace.

In the fibrosis phase, it is useful to combine brace treatment with exercise consisting of passive and active movement assisted by a physical therapist. The physical therapist should be informed on the range of motion gained in the operating room and on the risk of instability.

In case of skin problems or ulnar nerve symptom onset, the patient should be instructed to contact the doctor promptly.

Through an infraclavicular or axillary block with continuous infusion of local anesthetic and also the possibility to plan boluses, it is possible to achieve appropriate analgesia of the elbow region in the postoperative period to allow effective rehabilitation therapy.

According to personal experience, in some cases regional analgesia managed by the patient can also be continued at home, usually for 3–7 days, but in some cases we have continued it for up to 3 weeks.

43.5 Mobilization Braces: Limits and Alternative Treatments

It is important to know that braces, particularly the mobilization ones, present several limits: the braces are expensive, they are required to be carefully adapted to the patient's arm, and they do not always fit correctly. The brace is time consuming for the related caregivers, and at least for the first phases, frequent follow-up exams are usually necessary. In fact, the brace being a removable device, managed for a long time at home, complete information, a total understanding, and full collaboration of the patient are mandatory. Ulnar nerve irritation is possible, and the presence of skin damage is possible especially after surgery. Moreover, the brace may need to be modified during this time, according to modifications of swelling, pain, and progress made.

Despite the improvement in the designs and in the materials obtained in the last years, elbow braces can make some daily activities difficult to perform and are often felt cumbersome and heavy to wear by the patients.

Alternative treatments for elbow stiffness are:

- Occupational and/or physical therapy without bracing under the supervision of the physical therapist to avoid that an uncontrolled therapy may exacerbate pain and inflammation, inhibiting rather than facilitating mobilization
- CPM: Its use is indicated only in the first phases; if the stiffness is structured, its use is not indicated.
- Serial casting: The treatment is time consuming, and this technique was used mostly in the past, poorly tolerated by the patients because it immobilizes the arm, interferes with the performance of daily activities, and may cause stiffness in the opposite direction.
- Examination or forced manipulation under anesthesia: We have concerns about the possible associated complications such as fractures, ulnar nerve injuries, instability, and development of heterotopic ossification.
- Surgical release, performed open or arthroscopically.

Conclusions

The braces are effective devices in the rehabilitation of many elbow disorders. They are usually better tolerated by the patient with respect to the heavy arm cylinder casts used in the past. With respect to casts, braces can allow the permitted movements of the elbow, protecting it from dangerous ones, in this way reducing the risk of stiffness, venous stasis, and reflex sympathetic dystrophy.

In elbow rehabilitation, the brace constitutes a possible device to contrast the risk of instability or stiffness. In elbow stiffness, the brace is a therapeutic device that makes it possible, in selected cases, to treat elbow contractures conservatively. Also, after soft tissue release, the brace can be useful to maintain the range of motion gained in the operating room. In elbow stiffness treatment, the patient should always be informed of how long the treatment may take.

In order to ensure that the rehabilitative treatment with the brace is successful, it is almost always necessary to combine many competencies at the same time: the orthopedic or physiatrist for the correct prescription, the pain control and the follow-up, the orthopedic technician to build or adapt the cast, and the physical therapist to combine the brace with the physical therapy. For this reason it is important that the brace is not thought of as an alternative to the physical therapist. On the contrary, the use of the elbow brace should be included in a global rehabilitation program shared between the patients and the caregivers involved. The authors think that the new classification they propone can simplify the communication between the different professional figures involved (Table 43.1).

Despite the improved design and materials, for many patients the discomfort caused by a brace that does not always fit perfectly, the long periods it has to be worn, and the difficulty in sleeping and carrying out daily activities wearing the brace do not infrequently decrease their compliance and therefore the effectiveness of the brace. Other limitations of the braces in elbow physical therapy are that they are expensive and are time consuming, requiring frequent follow-up exams.

Despite these limitations in our experience, the use of the brace in elbow physical therapy has improved results in our patients.

In the future 3D-printing technology will permit to create personalized casts and braces that will be lighter, less bulky, and water-friendly making more comfortable their long-term wear.

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