Hand and Wrist Injuries In Combat Sports

A Guide to Diagnosis and Treatment

Riccardo Luchetti
Loris Pegoli
Gregory I. Bain *Editors*

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Foreword

I always used to say that without doctors ringside any fighting show could not go on and without a proper specialist for any anatomical region a fighter should not even train.
Seriously, in game sports such as kickboxing, mixed martial arts (MMA), boxing, and other combat sports, the care of the wrists and hands is the main issue for all fighters.

For a fighter just to know that his hands have or have had a problem can affect the final result of the fight.

The protection of the hands with wrapping during a fight is useful only if, from the very beginning of the athlete's career, he has been followed by somebody who is a specialist.

This is the case for those hand surgeons and therapists that, together with the expertise of the trainer and athlete, are able to create the best care for the hands of champions in combat sports.

Among these champions are Mustapha Haida (International Sport Karate Association [ISKA] World Champion) and Giorgio Petrosyan (the greatest kick boxer of all time, as the sports press is calling him), and many others. Giorgio has broken his hands several times, but with "his" hand surgeon and hand therapist he has been able to remain at the top up to now.

Apart from the surgical and rehabilitative points of view, it is mandatory to focus on the mental side: the main weapon of any sportsperson. If you do not feel sure of your best weapon you will never get the best performance in sports. Giorgio Petrosyan has been so influenced by the care of his surgeon as to write a book on his story entitled *With my hands*.

To the men and women who take care of the good health of the fighters, we all need to say thank you, because without them we would not have such great champions, great performances, and huge shows. Let us always remember what occurs behind a fight and before getting to the fight.

Fight1, Milan, Italy Carlo Di Blasi

Preface

The art of combat exposes athletes to injuries of all parts of the body, with these injuries sometimes even being lethal. The importance of the hand in martial arts is fundamental for an offensive or defensive grip. As a group of expert hand surgery specialists, some who have also been competitive athletes, we considered the management of these injuries, obviously not only for their treatment, but also for their prevention. We have therefore founded, thanks to the brilliant intuition of Dr Loris Pegoli, an International Society dedicated to this purpose, called the International Society for Sport Traumatology of the Hand (ISSPORTH).

Each of us, as experts, knows how difficult it is to treat these injuries, and how the non-resolution of the injury or suspension from competitive or sporting activity is dramatically not well accepted by the competitors. However, there is a moment in life in which competitive sporting activity must be limited or abandoned and it is very difficult to make this clear to the athlete. Fortunately, Mother Nature helps by giving us signals. Previous injuries now become chronic, and increasing age does not allow more than doing exhausting workouts aimed at competition, and recovery becomes increasingly longer with pauses during which sometimes there is no training. So now it is the athletes' time to move on to fun training and teaching techniques, like the Kata techniques [1], allowing them to still remain athletes (Figs. 1 and 2).

Fig. 1 Athlete still active

Fig. 2 Athlete at the end of their career

I thank all the authors of this book and the co-editors Dr Loris Pegoli and Professor Gregory I. Bain for their help in the drawing up of this book.

A special thanks to the late Elisa Geranio, who suggested this title and encouraged me to produce this book and had been supporting me, until the moment of her premature passing away, when the book was almost published.

Rimini, Italy Riccardo Luchetti

Reference

1. Fukuda K. Ju No Kata: a Kodocan Judo textbook. Berkeley, CA: North Atlantic Books; 2004.

Contents

Introduction

Although the earliest evidence of martial arts goes back millennia, the true roots are difficult to recognize mainly because they developed in countries that have been historically isolated from the Western world for ages. Inherent patterns of human aggression which inspire practice of mock combat (in particular wrestling) are doubtlessly inherited from the prehuman stage and were made into an "art" from the earliest emergence of that concept.

Specific martial traditions become identifiable in Classical Antiquity, with disciplines such as shuai jiao, Greek wrestling, or those described in the Indian epics or the *Spring and Autumn Annals* of China.

The earliest evidence for specifics of martial arts as practiced in the past comes from depictions of fights, both in figurative art and in early literature. The oldest work of art depicting scenes of battle, dating back 3400 BCE, was the ancient Egyptian paintings showing some form of struggle. Dating back to 3000 BCE in Mesopotamia (Babylon), reliefs and the poems depicting struggle were found. In Vietnam, drawings and sketches from 2879 BCE describe certain ways of combat using sword, stick, bow, and spears.

Some early examples are the depiction of wrestling techniques in a tomb of the Middle Kingdom of Egypt at Beni Hasan (c. 2000 BCE) and pictorial representations of fist fighting in the Minoan civilization dating to the 2nd millennium BCE.

In ancient China, Yellow Emperor (2698 BCE) is described as a famous general who, before becoming China's leader, wrote lengthy treatises on medicine, astrology, and martial arts. Literary descriptions of combat began in the 2nd millennium BCE, with mention of weaponry and combat in texts like the Gilgamesh epic or the Rig-Veda. Detailed description of Late Bronze Age to Early Iron Age hand-to-hand combat with spear, sword, and shield is found in the Iliad (c. 8th century BCE) and also the Mahabharata. In both China and India, artifacts from 2000 to 4000 years old have been found as well, with paintings of people striking possible martial arts poses. *Qigong*, one of the oldest systems that may be considered a martial art, is believed by some historians to be 5000 years old or older, originating in ancient China.

Martial arts involve intellectual concepts as well as physical techniques and have been influenced by many of the religious and philosophical systems of the East.

Martial arts were largely unknown to the Western world as far as 1945, when a few American and British veterans of World War II brought back

Japanese martial arts from occupied Japan and little by little spreading all over the world.

This short review of history shows how the art of fighting has been in the blood of human being since ever, but in the last decade the world of martial arts got more and more popular thanks to the interest of media and social networks attracting the interest of sponsors and business company making the fighter not only an athlete but also an investment, moving billions of dollars a year.

The goal of this book is to make a review of the most common injuries of combat sports, focusing on the surgical treatment, as well as on their prevention and on those elements that might help the athlete to return to fighting, such as physiological support and mental training.

The most known worldwide professionals dealing with these subjects gathered to try to give the most extensive description and support to surgeons, athletes, trainers, and professionals related to the world of martial art, strongly supported by the International Society for Sport Traumatology of the Hand (ISSPORTH). The latter is the first official International Society, founded by professionals from all over the world, whose goal is the education of wrist and hand conditions from prevention to treatment.

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1 Hand and Wrist Injuries in Kick Boxing

Loris Pegoli and Alessandro Pozzi

1.1 Introduction

Kick boxing is a relatively young practice compared to other martial disciplines. Its origin is dated back in 1960 in Japan, but for few years, it was not recognized as a real distinct discipline. In 1993 the first tournament, called K1 (where K stands for karate, kempo and kick boxing), was organized in Japan. Since then, an exponential interest arose around this discipline that nowadays is considered to be one of the practised amongst martial arts. The number of kick boxing-related injuries grew over time following the constant rise of the participants (Fig. 1.1) [1].

Focusing on kick boxing-related injuries, the first important distinction has to be done between ligamentous and skeletal lesions, not only because of their anatomical difference but mainly because of their aetiology [2]. In fact while in high-trained or high-level athletes, bony structures are more involved, amongst newbie, ligaments are the first affected structures. This statement comes from our experience in the evaluation of fighters as well as from a study performed on 2439 fighters practicing kick boxing, Muay Thai, boxing and full contact [3].

In this chapter we will describe the lesion, its aetiology, its treatment and, where possible, the way to prevent it (Table 1.1).

Fig. 1.1 Unknown artist - from Le Musée absolu, Phaidon

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Table 1.1 The table shows the most common injuries of kick boxing divided for group, showing the most common mechanism of injury alongside with the suggested treatment and the recovery time

		Mechanism of injury	Treatment	Immobilization	Postop rehabilitation	Medical boxing bag	Boxing bag contact	Full return
Ligamentous lesions	Fibrocartilage complex	Hook	Repair or reconstruction	4–6 weeks	2 months	6 weeks	3 months	3 months
	Scapholunate	Uppercut	Repair or reconstruction	6 weeks	2 months	6 weeks	3 months	3–4 months
	Luno-triquetrum	Uppercut	Repair or reconstruction	6 weeks	2 months	6 weeks	3 months	3–4 months
Skeletal lesions	Fractures	Direct trauma	Conservative or surgical	4 weeks	1 month	2 weeks	2 months	3 months
Soft tissues lesions	Metacarpophalangeal subluxation	Repetitive direct trauma	Carpometacarpal fusion		1 month	1 month	2 months	2 months
	Synovitis	Repetitive direct trauma	Conservative or surgical	4 weeks	1 month	From 2 weeks to 1 month	2 months	3 months
	Extensor hood lesion	Single trauma	Surgical repair	3 weeks	6 weeks	1 month	2 months	3 months

1.2 Ligamentous Lesions

As mentioned above these lesions occur mainly in amateur fighters, even in the presence of a proper wrist and hand wrapping that we remind should be mandatory in any single training session [4, 5].

1.2.1 Fibrocartilage Complex Lesion

This structure is a complex ligament apparatus whose role is to give stability to the distal radioulnar joint during rotational movements of the wrist (the so-called pronation and supination) (Fig. 1.2 and 1.3). During a hook or an uppercut (Fig. 1.4), the forces of pronation and supination combined with a flexion of the wrist might cause its lesion. Clinically the patient refers pain at the ulnar aspect of the wrist, during rotation, and an instability of the radioulnar joint can be present (mandatory to compare to the other side for proper diagnosis). The correct diagnosis starts with the location of pain, usually at the level of ulnar aspect of the wrist and the comparison of the stability of both radioulnar distal joints with the ballottement test. Some special evaluation, such as the so-called waiter's test in which the wrist is bended in maximal extension, can provoke pain. The second step is the evaluation of comparative radiograms taken in standard anteroposterior and latero-lateral view. In this latter evaluation, we are not able to see the ligament itself, but an anatomical difference between the two sides, in particular a dorsal subluxation of the ulnar head, may give a strong suspect of a lesion (Fig. 1.5). If still a doubt is present, a magnetic resonance imaging (MRI) is suggested [6, 7]. The only certain evaluation to identify not only the lesion but also its location and extension is an arthroscopy. The latter allows to locate the lesion at its proximal insertion (foveal attachment) or at the distal one. In case the lesion is confirmed, arthroscopy might be also the tool to repair or reconstruct it in case of a chronic lesion. Many different surgical procedures have been described, from arthroscopically assisted inside-out or all-inside techniques to open procedures [8]. The postoperative protocol, considering the immediate immobilization of about 4–6 weeks and following rehabilitation, might take up to 3 months. There might be some residual deficit of the maximal pro-

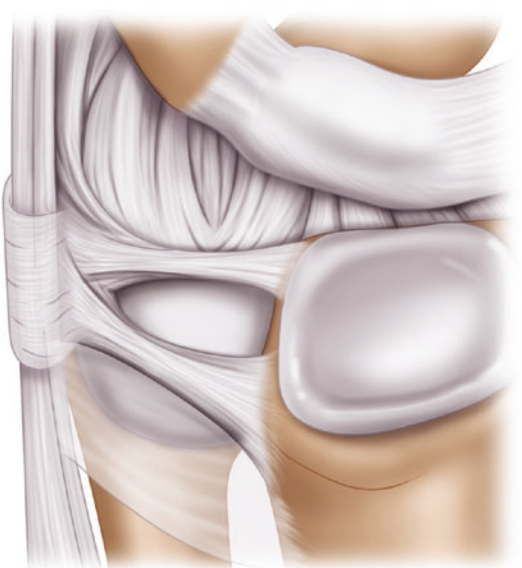

Fig. 1.2 Drawing of the triangular fibrocartilaginous complex (TFCC) from the radio-carpal joint

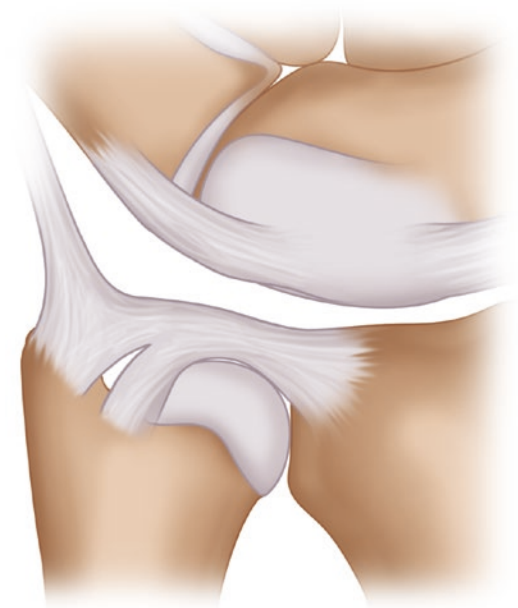

Fig. 1.3 Lateral view of the triangular fibrocartilaginous complex (TFCC), please note from this view the double insertion that this structure has on the tip of the ulnar styloid and on the fovea

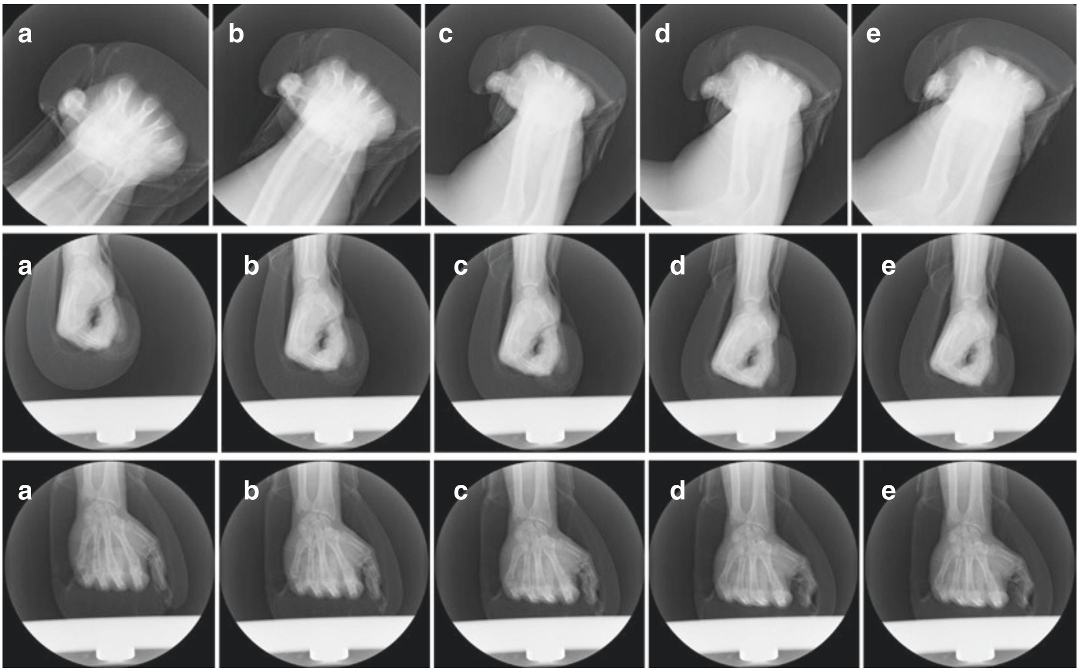

Fig. 1.4 The three stripes represent series of radiograms taken during three different kinds of punches; the first one is the hook, the middle one is the uppercut, and the last one is the straight punch. Please note that the radiograms were taken from (**a**) before the hit to (**b**) first contact, then to (**c**) load application on the surface, to (**d**) maximum load and finally to (**e**) release of pressure

nation and supination, but usually fighters are able to return to their previous activity.

1.2.2 Scapholunate Ligament Lesion

This lesion represents the most serious soft tissue lesion for a fighter. This ligament is one of the most important in maintaining the strength and stability of the wrist. It connects the scaphoid and the lunate bones that, together with the second carpal row, allow the flexion and extension of the wrist as well as radial and ulnar deviation (Fig. 1.6). Furthermore, it supports all the loads after a punch is given [9, 10].

There are different degrees of the lesion, and the proper grading is mandatory to give the correct indication for its treatment. Diagnosis starts with an accurate clinical examination that can reveal pain at the dorsal level of the radiocarpal joint, limitation of the range of motion in flexion and extension of the wrist and, sometime, a typical click during the so-called Watson's test. During this procedure the wrist, positioned in slight extension, is grasped putting the thumb over the scaphoid tubercle (volar aspect of the palm) in order to prevent the scaphoid from moving into its more vertically oriented position in radial deviation. The patient's wrist is then moved from ulnar to radial deviation. It is often possible to feel a significant *clunk*, and the patient might experience pain if the test is positive.

With a comparative radiograph examination in standard anteroposterior, latero-lateral views, associated with specific views such as the pencil view or ulnar deviation, one can visualize, especially in advanced grade of the lesion, an increase of the scapholunate space (Fig. 1.7), suggesting the lesion. An MRI can often confirm the diagnosis, but the gold standard evaluation to give a proper diagnosis and staging is to perform a [11] diagnostic arthroscopy.

In acute lesions a primary repair of the ligament is indicated. Many surgical options have been described, both arthroscopic and open. In chronic lesions, considering chronic a lesion after about 3 months, the kind of technique is chosen

Fig. 1.5 Lateral radiograms of a wrist showing in the picture (**a**) a normal wrist, while in the picture (**b**) a dorsal ulnar subluxation can be appreciated as pointed by the white arrow. This is an indirect sign of lesion of the fibrocartilage complex

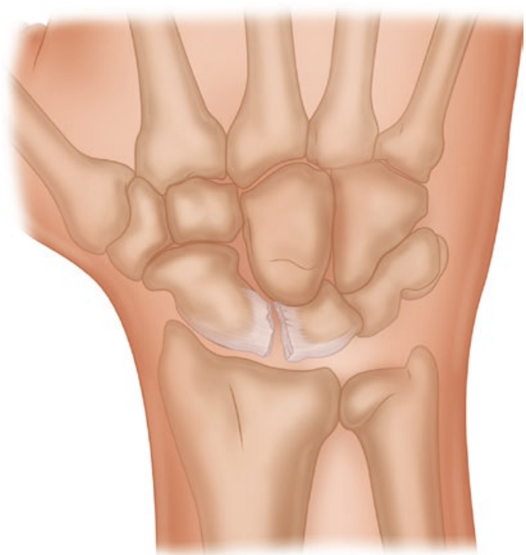

Fig. 1.6 Schematic representation of a wrist with evident rupture of the scapholunate ligament. Note the opening of the scapho-lunate interval

according to the cartilage status. If no cartilage damage is present, a reconstruction of the ligament can be performed. In case this lesion had been underestimated, a progression of the arthritic changes may proceed with a collapse of the carpal bone (typically the capitate bone) (Fig. 1.8). The final result is an impossibility to restore the normal anatomy, and only salvage procedure, such as proximal row carpectomy or limited carpal fusion, can be performed, leading the athlete to stop his career. The postoperative protocol, considering the immediate immobilization of 6 weeks and following rehabilitation, might take up to 3 months. There might be some residual deficit of the maximal extension and flexion, and despite a good result of the procedure, an average percentage of about 50% of the patients are not able to go back to fight at their original level.

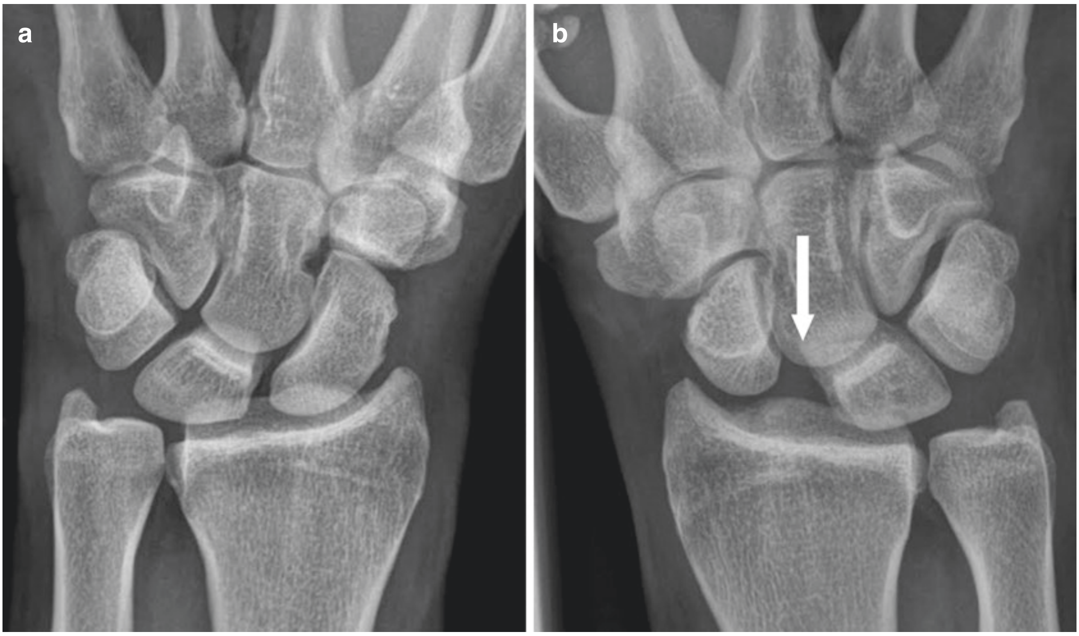

Fig. 1.7 Anteroposterior radiograms of a left (**a**) and right (**b**) wrist of the same athlete. The radiograms were token asking the patient to close his hands tight. As pointed by the arrow

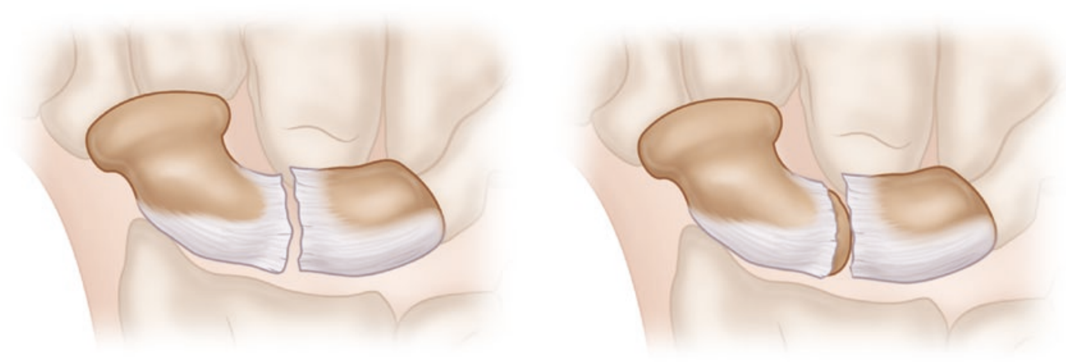

Fig. 1.8 (**a**) (Left side) Lesion of the scapholunate ligament, please note that the insertion of the ligament are preserved on both the scaphoid and the lunate. (**b**) (Right side) Detachment of the scapholunate ligament, where the ligament retains the attachment on the lunate but not on the scaphoiod

1.2.3 Volar Plate Lesion

The volar plate is a strong elastic structure located palmar at the fingers whose role is to avoid an overextension of the phalanx. Its lesion is quite rare, but it can be seen during training in paos users. A lesion of the volar plate can be isolated or associated with a fracture of its attachment. In the first case, primary repair can be performed, while in the latter, if the bony fragment is <20% of the articular surface, the treatment consists in an immobilization for few days, to prevent oedema, followed by an eight-shaped custom-made splint, whose role is to allow flexion of the finger and avoid extension. In case of a bigger fragment, the condition has to be treated like a fracture by different kind of surgical fixation procedures. Usually full recovery can be achieved.

1.2.4 Carpometacarpal Capsular Lesions

This condition, commonly known as *sore knuckles,* has been reported, but it is not so common in kick boxing compared to other sports such as boxing, where only the upper limbs are used, or mix martial arts where the protection for this anatomical area is thinner [12–15]. A specific description is reported in Chap. 20.

1.3 Skeletal Lesions

1.3.1 Metacarpal Fractures

Fractures affect mainly the metacarpal bones and amongst these the fifth and fourth (Fig. 1.9). The most involved site of fracture is just proximal to the metacarpal head. Fractures may happen mainly for a direct trauma (both giving a punch and protecting from a punch or kick), but in the dynamic of the lesion, the torsion forces applied by the intrinsic muscle play also an important role. The strength needed to cause a fracture is important; this is the reason why it is easier to sustain a broken bone during a match or sparring. In case of a non-displaced fracture, the treatment may be conservative with immobilization in custom-made splint for the time of bony callus formation (about 4–6 weeks).

Fig. 1.9 Antero-posterior radiogram of a hand that shows fractures of the fourth and fifth metacarpal bones as pointed by the white arrows

It is important to underline as in case of conservative treatment the return to the fighting activity may be longer because of the need to give the callus time to get stronger [16]. Full return, with no limit in punching the boxing bag, is usually allowed in 3 months' time. In case of displaced fracture or in those patients who decide to have a surgical treatment, even in case of non-displaced fracture, the return to training can be faster. If the surgical decision is the option of choice, the surgeon should be very careful about the kind of fixation to choose and how to position it. Plates should be little oversized as to furnish stability and endurance to the bone while it is healing (Fig. 1.10). Furthermore, the plate should be as long as possible to cover the metacarpal bone in all its length: a shorter plate might create a weak point between its end and the bone creating forces that might lead to a secondary fracture at the passage site.

1.3.2 Scaphoid Fractures

Another bone that can be involved is the scaphoid. This bone is extremely important being the one that represents the 60% of the radiocarpal joint though a higher loading area while punching. Because of its peculiar features (80% of the bone is covered by cartilage, the poor vascularity), sometime a fracture is difficult to be detected at the first radiological evaluation. Though in case of pain at the level of the so-called snuff box or at the scaphoid tubercle, an immobilization and new radiographs are strongly suggested after 7–10 days for a proper diagnosis. Sometime if doubt still persists, a CT scan should be performed [17]. The guideline of treatment follows the one of the other bones as written above. A conservative treatment can be done in case of non-displaced fracture, while in case of displaced

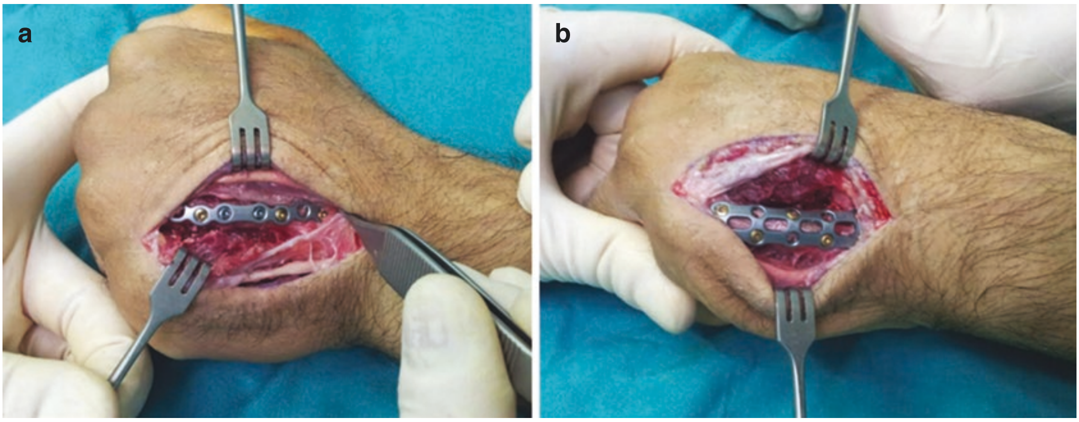

Fig. 1.10 (**a**) Picture of the surgical treatment with plate and screws of the fracture of the fourth metacarpal is showed in Fig. 1.9 and (**b**) surgical treatment of the fracture of the fifth metacarpal is showed in Fig. 1.9

fracture a surgical procedure is mandatory [18]. There could be then borderline situations in which, despite non-displaced fractures, the patient wants a faster recovery or return to activity. In these cases, it is possible to proceed with a percutaneous fixation of the bone with compression screws: a fast and easy procedure.

Today special medical boxing bags are available on the market. These special devices allow to hit the bag much earlier than the standard one deadening the hit of the punch but keeping the upper limb muscular chain, with the great advantage to anticipate the return to fighting activity looking also at the rest of the body [19].

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2 Proximal Phalangeal Joint Injuries

Simon MacLean and Gregory I. Bain

2.1 Introduction

The PIP joint is frequently injured in combat sports. The severity of the injury is frequently underplayed by the coach or manager—colloquial terms include "jammed finger" or "stoved finger." The patient often presents late—making conservative and surgical management challenging. McCue proposed the term "coach's finger" for the delayed presentation in these cases [1].

The PIP joint has a large range of movement and is ideally located to provide dexterity and versatility. For this reason, it is the most important joint in the hand. It acts as a highly constrained hinge—preventing translation and rotation yet allowing a range of movement of approximately 110°. The shearing and axial forces on the joint are high at the time of impact as the middle phalanx acts as an intercalated segment—transmitting force from the end of the digit to the PIP joint.

For everyday tasks, the functional range of motion for the MCP, PIP, and DIP joints, respectively, are 19–71°, 23–87°, and 10–64° [2–5]. An injury encroaching on this range will have a functional impact. Combat sports often require a clenched fist or extended digits. The range required to perform function in this setting is higher. In addition, the combat athlete requires strength, stability, and a pain-free PIP joint. This requires the physician to have a thorough understanding of the anatomy, kinematics, treatment options, and operative techniques to optimize function in these high demand individuals [3, 4, 6].

2.2 Clinical Assessment

History is crucial. A prescription for treatment is based on the timing of the injury and the functional demands of the patient. Stiffness is a common sequelae to PIP joint injuries, and the ideal treatment allows for a congruent, stable articulation with an early full range of motion.

Swelling is common. Tenderness on the "three-dimensional box" allows anatomical location of the injury; volar tenderness suggests volar plate injury, and medial or lateral tenderness suggests collateral injury. Dorsal tenderness

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suggests an injury to the central slip. Gross swelling or marked deformity is more likely to represent a dislocation or fracture at the joint.

Stability assessment requires a metacarpal local anesthetic block to reduce pain and flexor spasm [7]. Comparison should be made to the adjacent and contralateral sides. A full range of stable motion in the joint signifies functional stability. The last 20° of extension is the most critical and the point where the joint is most likely to be unstable. The volar plate is tested by passive hyperextension at the joint. Pain and hyperextension compared to the contralateral side represent a volar plate injury. The collaterals should be tested with varus and valgus strain at extension and 30° flexion [8].

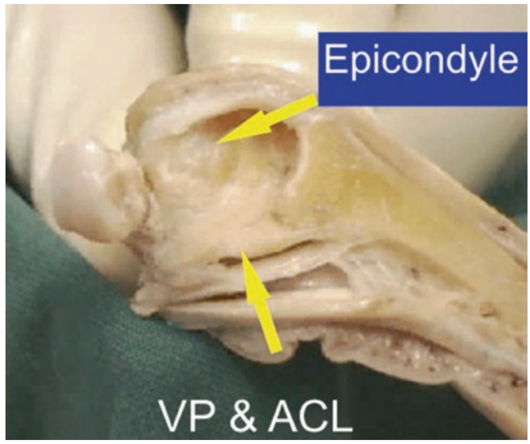

Fig. 2.1 The "Critical Corner"—the convergence of the distal volar plate and collateral ligament. *VP* volar plate, *ACL* accessory collateral ligament. Copyright Dr. Gregory I. Bain

2.3 Radiographic Assessment

Plain radiographs are critical. A PA and true lateral radiograph are mandatory. The lateral radiograph reveals the volar or dorsal "lip" fracture. Fluoroscopy is another useful aid for dynamic assessment of the joint. The "personality" of the fracture can therefore be assessed. CT scans are often not required but can be used to aid operative planning by assessing extent of comminution as well as size and rotation of fracture fragments.

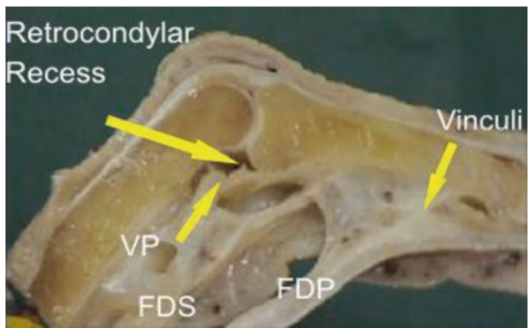

Fig. 2.2 A sagittal section showing the relationship between the PIP joint and volar structures. *VP* volar plate, *FDS* flexor digitorum profundus, *FDS* flexor digitorum superficialis. Copyright Dr. Gregory I. Bain

2.4 Applied Anatomy

The PIP joint is a hinge joint. A three-dimensional box is formed by the thick volar plate, the lateral margins attaching to the collateral and accessory collateral ligaments. The volar plate and flexor sheath support the volar aspect of the joint, and the extensor apparatus enhances the dorsal aspect. The area near the distal attachment of the volar plate and its convergence with the proper collateral ligament are known as the "critical corner" by Bowers (Fig. 2.1) [9]. The proximal extensions of the volar plate are termed the checkrein ligaments. The volar plate also provides attachment for the first cruciate pulley and A3 pulley. A sagittal section showing soft tissue relationships is shown in Fig. 2.2.

Dorsally, the central slip of the extensor apparatus attaches to the base of the middle phalanx, and its volar surface fuses with the capsular structures. Lateral bands are connected by the triangular ligament, which synchronize movement and prevent subluxation. The transverse retinaculum spans between the fibro-osseous tunnel and the lateral bands—preventing dorsal subluxation. The relationship between the soft tissues surrounding the PIP joint is shown in Video 2.1.

2.5 Injuries and Treatment Methods

2.5.1 Volar Plate Injuries

Injuries to the volar plate occur during forced hyperextension, where it becomes avulsed from the base of the middle phalanx [7]. With further hyperextension, a split can develop between the collaterals and accessory collaterals—the finger remains in hyperextension [10]. With further hyperextension, the middle phalanx dislocates dorsally and forms a “bayonet” position in relation to the proximal phalanx. At this point, two sides of the “box” have to be disturbed [7]. Reduction of the joint should then proceed; a metacarpal local anesthetic block is injected. Traction and manipulation of the digit then occur. Assessment of a stable range is then performed. The finger is then splinted but early flexion encouraged.

The finger is swollen and tender on the volar surface with a pure volar plate injury. With collateral involvement or fracture, there is generalized tenderness, and restriction in movement is marked. Radiographs are often normal.

Treatment should be patient-specific depending on the normal PIP joint laxity in that individual. In patients with hyperlaxity in the contralateral digit and >10° hyperextension, a figure-of-8 splint prevents swan-neck deformity. We advise leaving this on for 2–4 weeks. In patients with a normal range of motion of their PIP joints, we advise buddy taping, as they are more prone to developing stiffness.

Patients should avoid combat sports for at least 4 weeks (longer if still tender) and keep buddy taping on for a further 3 months.

Abnormal rotation seen clinically or on radiographs indicates either a fracture of the condyle or interposition of bone or soft tissue within the joint. The proximal phalanx can buttonhole through the volar plate and lie to the volar aspect of the flexor tendons which can block reduction [9]. The volar plate or collaterals can become interposed within the joint. An open reduction in these cases is often necessary.

Fracture avulsions occur when hyperextension and axial loading occur. The size and comminution can vary. These factors will affect the stability of the joint. The treatment of these injuries will be covered in a later section.

2.5.2 Collateral Ligament Injury

After sectioning the volar plate, the collateral ligaments can provide a stable range of motion between 30° and 110° [9]. A lateral force applied to the digit can cause avulsion of the collateral—usually from the origin on the proximal phalanx. This may occur on direct impact from a punch, kick, or grapple or on breaking a fall. Radial collateral ligament (RCL) tears are up to six times more common [7]. Propagation of the force causes separation of the accessory collateral ligament and distal avulsion of the volar plate [11]. On examination as with volar plate injuries, comparison should be made to the other digits and contralateral side [8]. Varus and valgus strain should take place at full extension and at 30° flexion (volar plate de-tensioned). If the joint can be deviated more than 20°, collateral ligament injury has occurred [11]. In the setting of lateral dislocation at the PIP joint, the joint can usually be reduced closed. If there is interposition of soft tissue and closed reduction is unsuccessful, open reduction may be necessary.

Management in buddy taping and early range of motion is usually sufficient. If a large fragment has been avulsed, open reduction and internal fixation may be necessary.

Chronic collateral instability at the PIP joint is rare, as stiffness is usually the prime concern with these injuries. Techniques described in the literature utilize palmaris longus or distally based slips of FDS, through bone tunnels or using suture anchors [12, 13, 14].

Our preferred method is to perform a preoperative examination under fluoroscopy to confirm the diagnosis. A lateral incision is made over the collateral ligament and the ligament stressed under direct visualization. If there is extensive bone formation from the avulsion, the ligament is released and the ligament reattached (Fig. 2.3).

If the ligament is deficient, then a ligament reconstruction can be performed using a palmaris longus graft. The osseous preparation consists of drill holes in the ligament attachment sites of the proximal and middle phalanges (Fig. 2.4). The ends of the tendon graft are advanced through each drill hole, and the graft is secured with 3 mm interference fit screws (Copyright Dr. Gregory I. Bain).

2.5.3 Central Slip Injury

This is the prime dorsal stabilizer and main extensor of the PIP joint. Injury to this structure occurs during forced hyperflexion, resisted extension, or laceration. The Elson test is used to test the integrity of the central slip (Fig. 2.5). The MCP joint is extended (e.g., over a table) and the patient asked to extend the PIP joint against resistance. The absence of extension force at the proximal joint and fixed extension at the distal joint is a sign of complete rupture of the central slip [15].

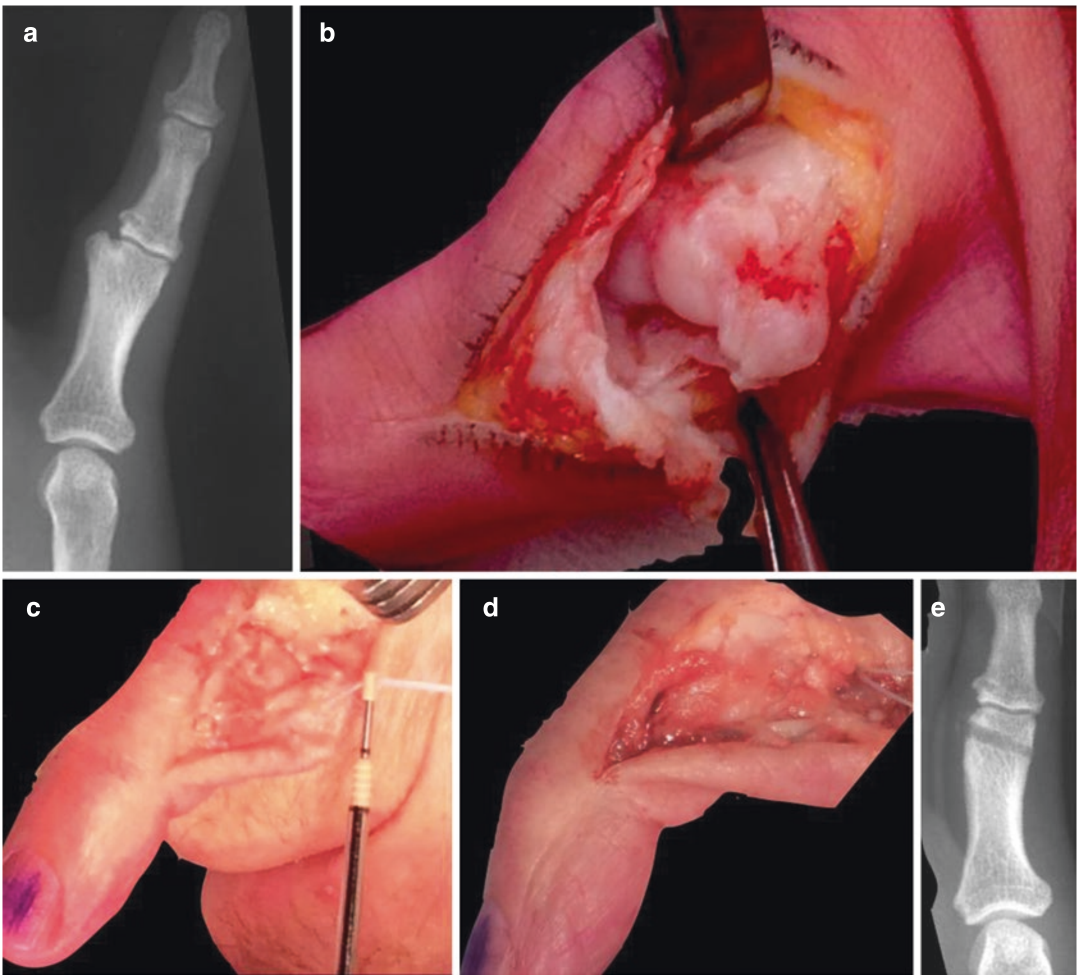

Fig. 2.3 Chronic radial collateral ligament injury in a 27-year-old basketballer, who presented with pain, clicking, catching, and instability with PIP joint flexion: (**a**, **b**) radiograph and clinical photograph of the traction spur at the attachment of the collateral ligament, (**c**–**e**) the spur is excised and the ligament reattached to the proximal phalanx with a suture anchor

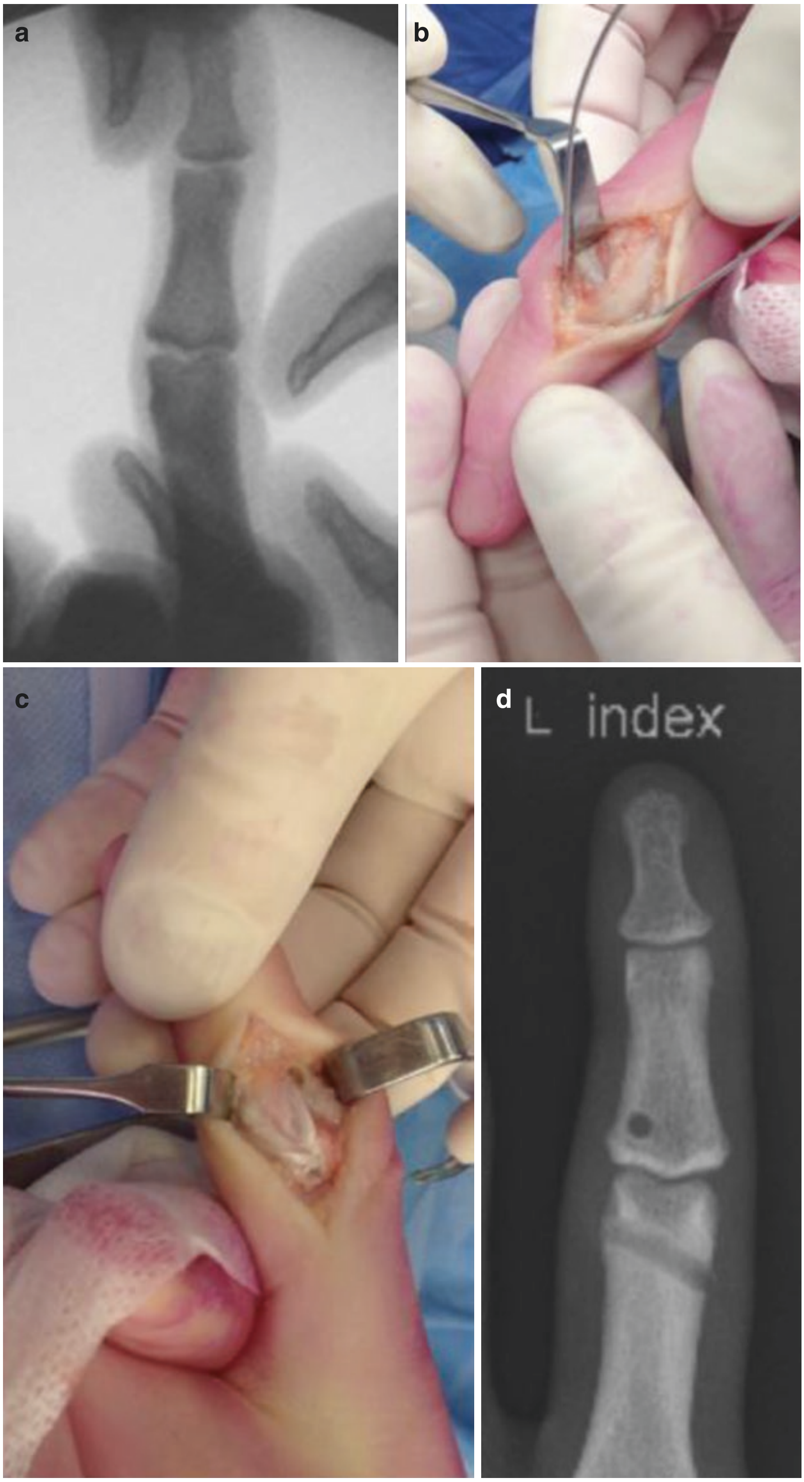

Fig. 2.4 CRCL—chronic radial collateral ligament injury in a 21-year-old off-spin cricket bowler. He presented with pain with stressing the collateral ligament, including when bowling. (**a**, **b**) Stressing the collateral ligament under fluoroscopy and after exposure of the ligament. (**c**, **d**) Collateral ligament reconstruction with palmaris longus tendon graft, which passes from dorsal to volar in the middle phalanx and then into the isometric point of the proximal phalanx, where it was secured with a mini-interference fit screw. (**e**, **f**) Range of motion at 3 months. Copyright Dr. Gregory I. Bain

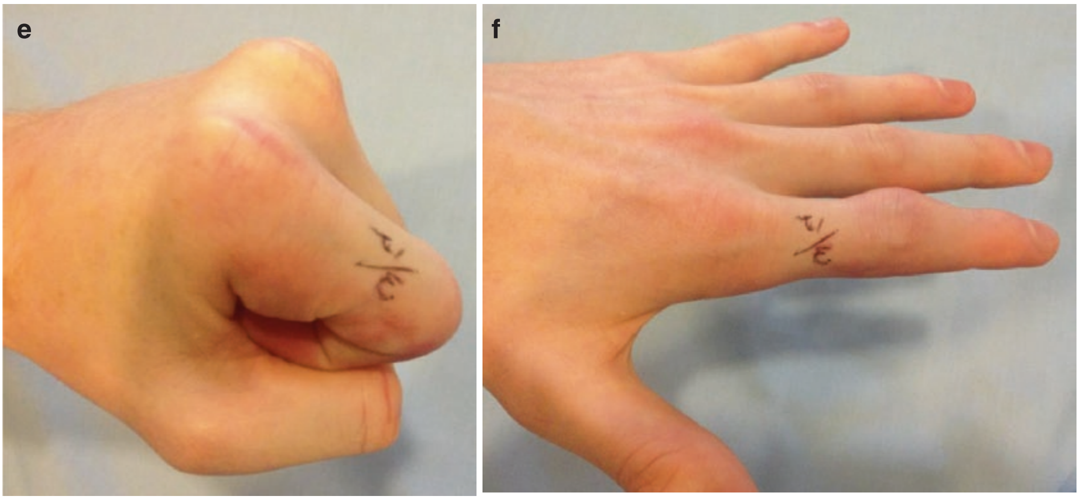

Fig. 2.4 (continued)

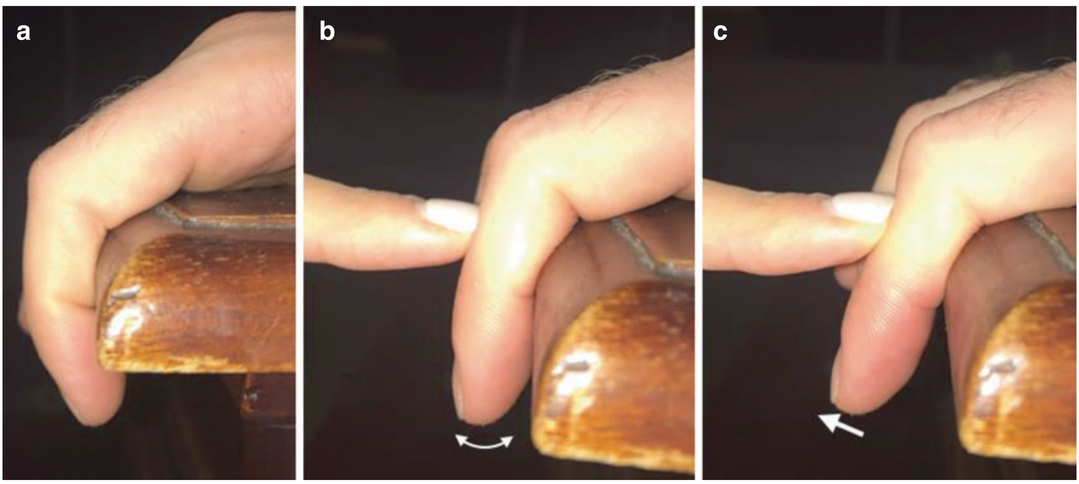

Fig. 2.5 The Elson test: The MCP joint is extended (e.g., over a table) (**a**) and the patient asked to extend the PIP joint against resistance. With an intact central slip, the DIP joint remains supple and passively mobile (**b**). The absence of extension force at the proximal joint and fixed extension at the distal joint is a sign of complete rupture of the central slip (**c**). Copyright Dr. Simon MacLean

Fracture avulsions will be covered in a separate section. For pure soft tissue avulsions, we prefer the use of a Capener dynamic extension splint for 6 weeks.

2.5.4 Dorsal PIPJ Fracture-Dislocations

With forced hyperextension *and* axial load, the volar plate will be avulsed with a fragment of bone—often impacted and comminuted. Stability of the joint is then dependent on the size of the fragment. Fractures involving <30% of the joint surface are considered stable and 30–50%—tenuous [16, 17]. If more than 50% involvement of the volar surface has occurred, the shaft subluxes dorsally as the distal collateral ligament is attached to the avulsed volar fragment. Smaller fragments <30% usually retain joint stability, and these can be managed in a dorsal extension-blocking splint [10, 18].

A “V sign” is a V-shaped space apparent on the dorsal aspect of the joint, on lateral radiographs. It is an important sign, as it indicates a nonconcentrically reduced joint [19].

The treatment ladder in unstable volar lip fractures is repair, reconstruction, and then salvage. The preferred treatment strategy depends on multiple factors. Patient factors include age, occupational and functional demands, time from injury at presentation, comorbidities, and preexisting arthritis and osteoporosis. Surgical factors include resources, training, and surgeon’s skill set. The ideal treatment option allows for articular surface reduction and early mobilization. Prolonged splinting leads to considerable stiffness and should be avoided.

If repair is undertaken, a volar approach through a hemi-Bruner’s incision is the author’s preferred method, as it allows good exposure of the joint but minimizes risk to the contralateral digital nerve and vessels. The sheath between A2 and A4 pulleys is excised, and the flexor tendons are retracted as described by Hamilton et al. [20]. The fracture lies on the dorsal aspect of the volar plate. If the fracture is not comminuted, anatomical reduction can be performed directly with pointed reduction forceps under fluoroscopy. Screws can then be used to fix a sizable fragment.

In cases of comminution, we perform a distally based “trapdoor” approach at the level of the PIP joint and elevate the fragment under the distal volar plate at the base of the middle phalanx. A beaver blade can be used to elevate any depressed articular fragments. Bone graft from the ipsilateral distal radius can be used to backfill the defect. If more exposure is needed, we “shotgun” the joint by releasing the proximal attachments of the collateral ligaments (Fig. 2.6). A low-profile volar buttress plate can be used to reduce and stabilize the fracture and indirectly the joint (Fig. 2.7). Excision of one FDS slip may be required. The volar plate is repaired, if necessary to the edge of the A4 pulley or FDS slips.

In a small series, good outcomes for strength, range of motion, return to work, and stability have been reported following fixation using screws or volar plates. This is a technically demanding procedure. The complication rate is as high as 39%, and the reoperation rate for hardware removal, tenolysis, and salvage can be significant [20, 21].

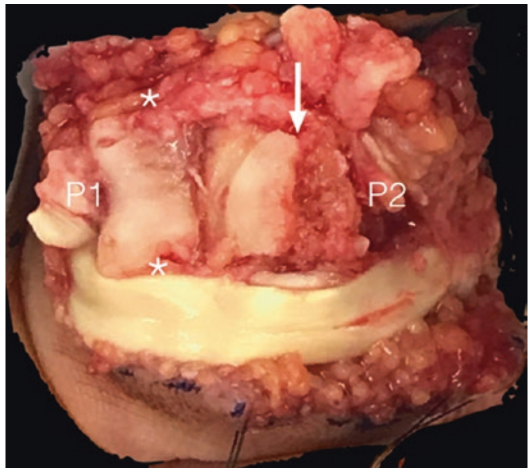

Fig. 2.6 The PIP joint can be “shotgunned.” This provides excellent exposure of the fracture (white arrow). Note the comminution and bone loss on the volar surface of the joint. The collateral ligaments are released from their proximal attachment (white asterisk). *P1* proximal phalanx, *P2* middle phalanx. Copyright Dr. Simon MacLean

If less comminution is present and the volar fracture can be reduced easily, an alternative surgical approach is laterally between the central slip and lateral bands. A pointed reduction clamp can be used for fracture reduction and screws placed in a dorsal to volar direction [22].

Abnormal finger rotation implies interposition of soft tissue or bone. The head of the proximal phalanx can buttonhole through the volar plate rupture and become locked between the two flexor tendons [9]. Volar plate, collateral ligament, or osteochondral fracture can block reduction. A widened joint space on radiographs can indicate soft tissue interposition. A closed reduction can be attempted, but an open reduction is usually required.

In cases where repair is not possible, several reconstruction options exist. Traditionally, *volar plate arthroplasty* has been a preferred option in cases with extensive comminution [23, 24]. This is especially likely if there has been a delayed presentation. The aim is to recreate the volar buttress that is lost from the

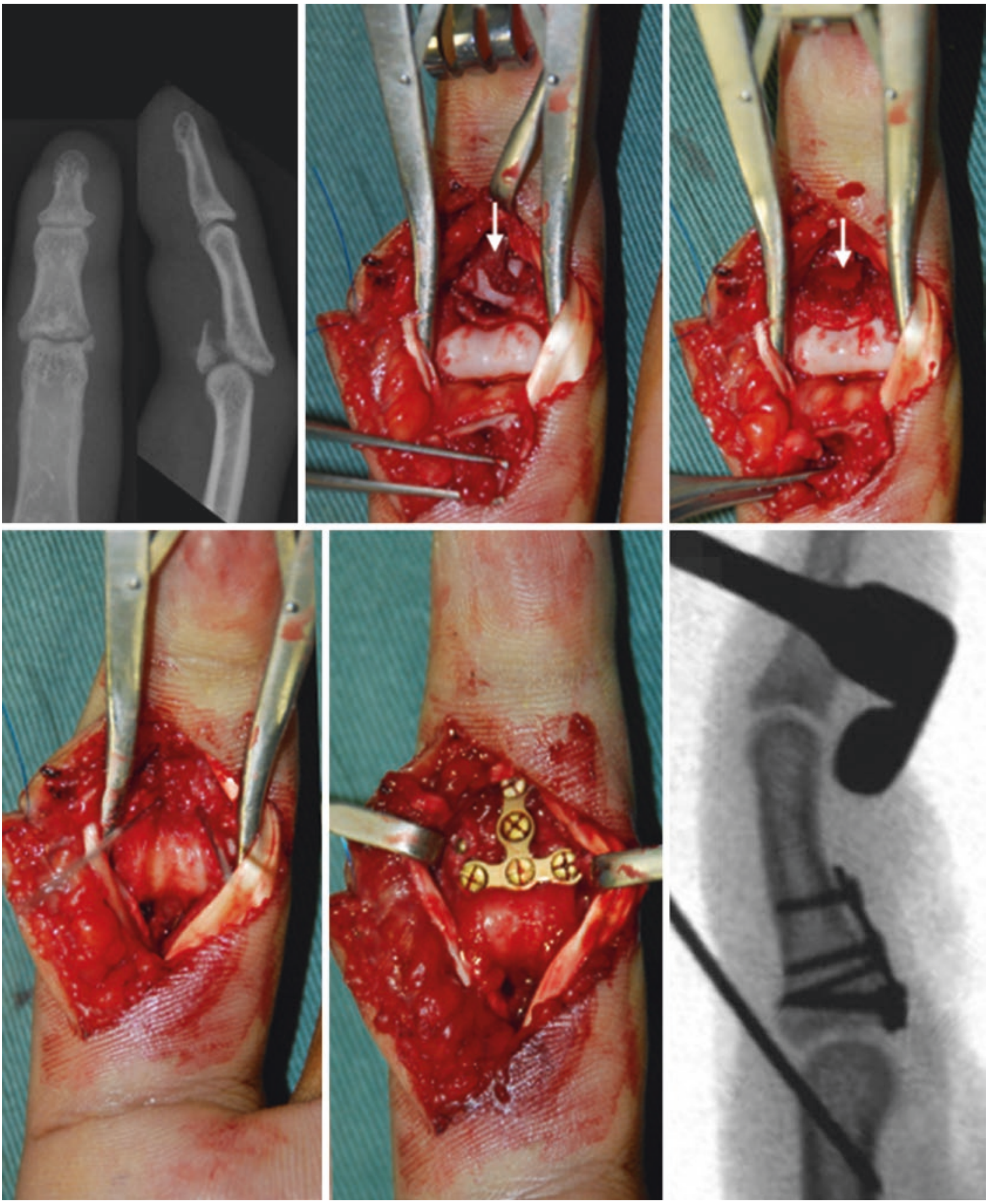

Fig. 2.7 Split-depression fracture subluxation. Via a hemi-Bruner's approach, the A3 pulley is excised. The volar plate has been released. The fracture has been reduced (white arrows) and stabilized with K-wires. A 1.3 mm ladder volar buttress plate stabilizes the fracture. Courtesy of Dr. Winston Chew

fracture at the base of the middle phalanx. The volar approach is performed as previously described, and the joint is "shotgunned." The checkrein ligaments are released. The middle phalanx base is debrided and the volar plate advanced with 3-0 PDS sutures in the leading edges [25]. Keith needles are used to advance these sutures through the middle phalanx to the "bare area" just distal to the central slip (Fig. 2.8). Alternatively, anchors or pullout

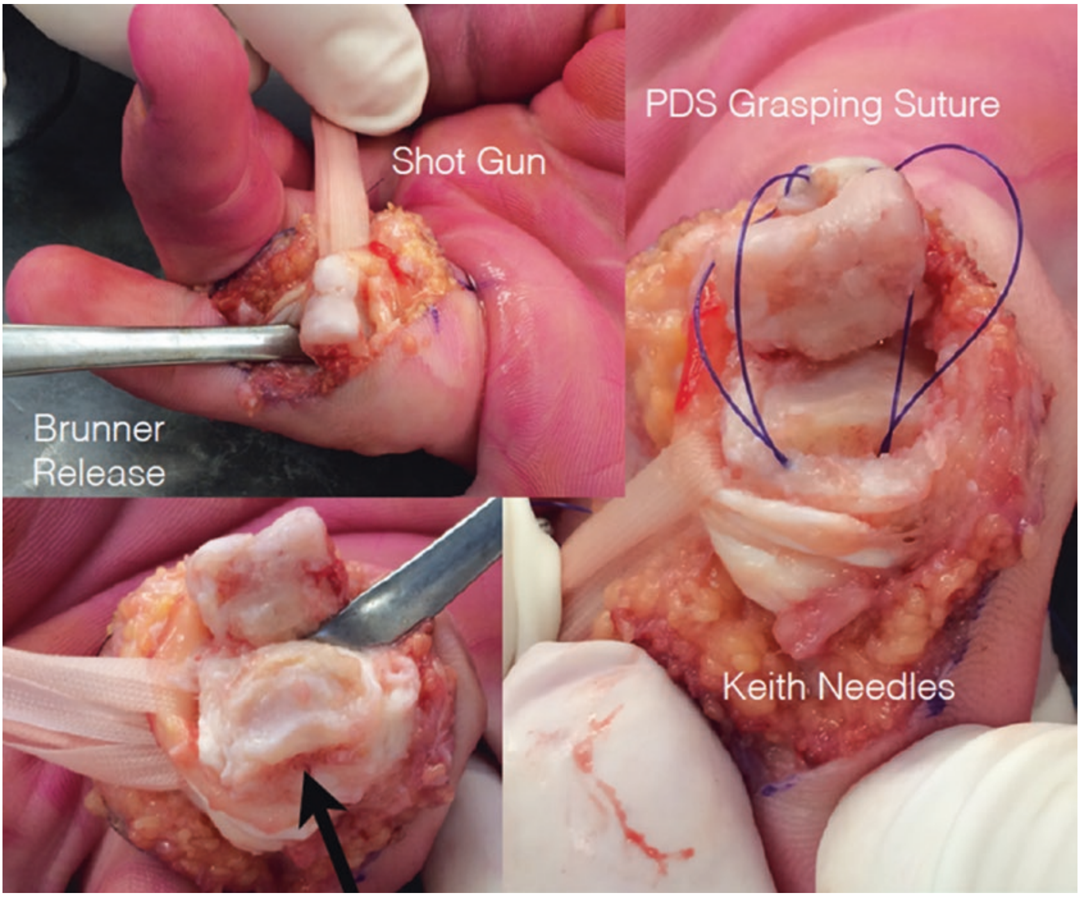

Fig. 2.8 Volar plate arthroplasty. A volar approach is performed, and the joint is "shotgunned." The fracture is debrided, and the defect is visualized (black arrow). The volar plate is advanced into this defect with PDS suture on Keith needles. Copyright Dr. Gregory I. Bain

wires can be used. Either a trans-articular wire, a dorsal extension-blocking wire, or a dynamic external fixator can then be used during healing [23, 25]. In a series by Eaton, an average 95° range of motion was achieved if the case was performed within 6 weeks (78° if after this period) [23]. In cases with >50% involvement of the joint surface, long-term stability of the joint is really difficult to obtain, and other options need to be considered [26].

The hemi-hamate arthroplasty was developed by Hastings [27] and is now a popular technique used to recreate a volar buttress to the PIP joint. The contour of the distal hamate at the carpometacarpal joints of the ring and small fingers follows the cup-shaped geometry of the proximal middle phalanx.

The volar approach to the PIP joint is performed as previously described (Fig. 2.9). A longitudinal incision centered over the fourth and fifth CMC joints is performed, with care taken to avoid the dorsal sensory branch of the ulnar nerve. The EDC is retracted to the radial side and the EDM to the ulnar side. An oversized osteochondral graft is obtained from the dorsal lip of the hamate, centered on the fourth and fifth metacarpals. The exact dimensions of the graft are marked on the dorsal hamate, and cuts are made using a fine oscillating saw (Fig. 2.10). The graft is placed into the defect and reshaped with a burr to form a concave surface proximally to recreate the volar buttress. We then temporarily transfix the graft with a K-wire and then fix the graft into place with two or three screws (1.2 or 1.3 mm

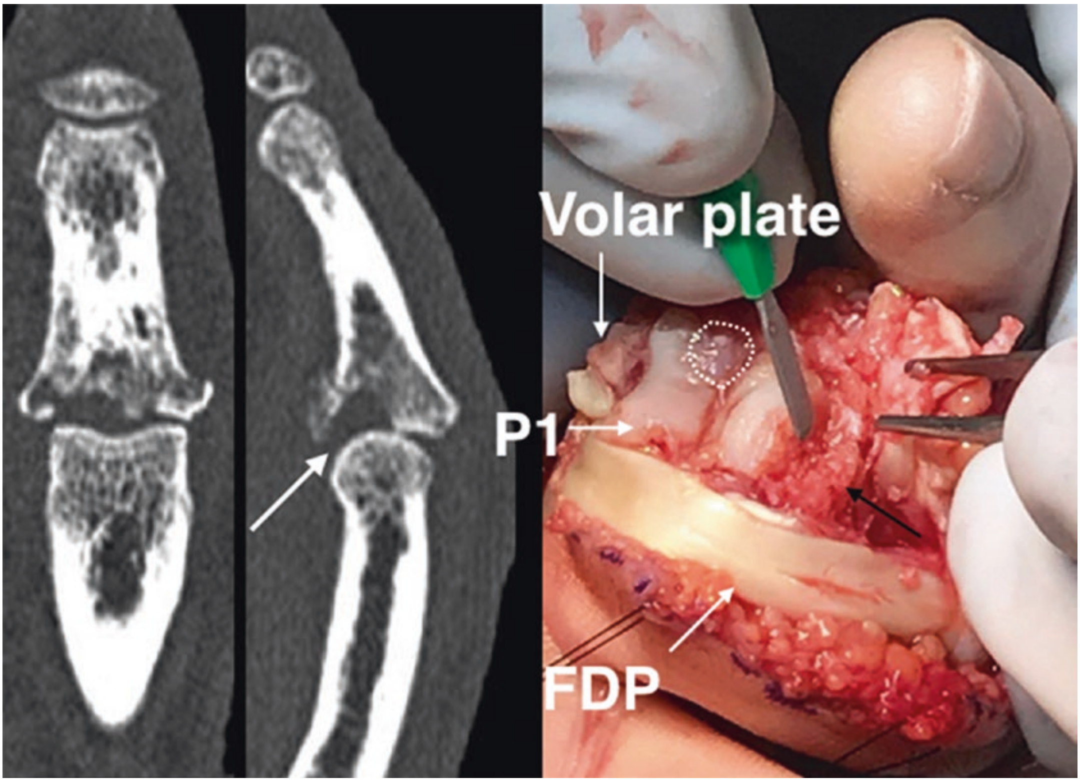

Fig. 2.9 Dorsal PIP joint fracture-dislocation with extensive comminution (>70% articular surface). Note the associated chondral damage on the head of the proximal phalanx (white dotted line). A beaver blade and burr are used to debride the fracture and provide straight flat edges for the hemi-hamate graft. Copyright Dr. Simon MacLean

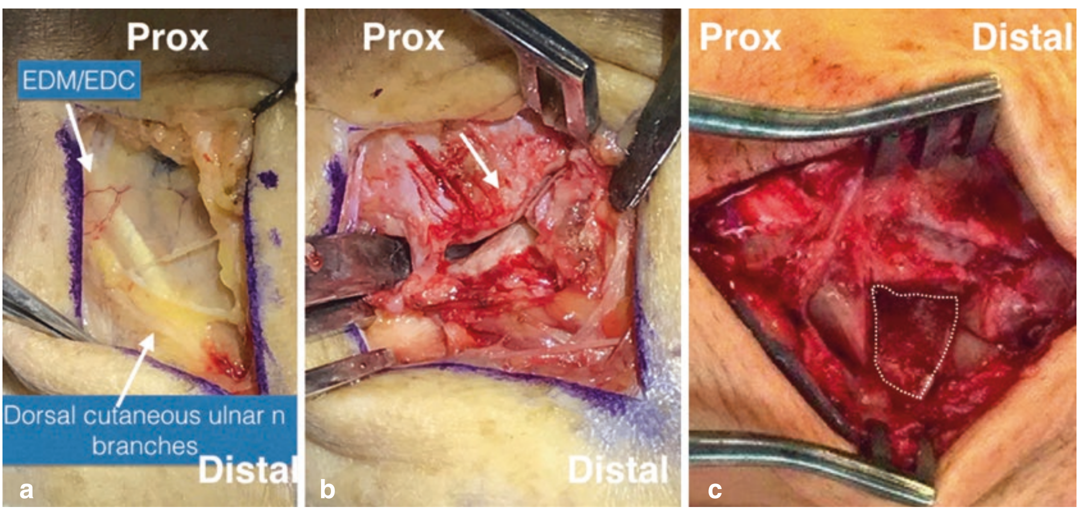

Fig. 2.10 Graft harvest: The fourth and fifth CMC joints are approached through a dorsal longitudinal approach (**a**). Care should be taken to avoid damage to the dorsal cutaneous branches of the ulnar nerve. EDM and EDC tendons are retracted. The joint is exposed (dorsal ridge—white arrow) (**b**). The graft is harvested after the dimensions of the phalangeal defect have been measured (dotted white line). The osteotomy should create a deeper trough proximally to allow the articular surface of the hamate graft to align properly at the PIP joint (**c**). Copyright Dr. Simon MacLean

diameter) (Fig. 2.11). The volar plate is then repaired as previously described. Joint reduction and adequate fixation are confirmed on fluoroscopy (Fig. 2.12). A small osseous step-off may be apparent due to the thicker articular cartilage of the hamate [27].

We encourage early active motion with a custom-made thermoplastic dorsal blocking splint for 3 weeks. Following this, stretching and more dynamic rehabilitation continue. Results in the literature report high union rates, up to 95% grip strength, and a functional range of motion in follow-up of 4.5 years [28, 29].

Several complications can occur. Nonunion of the graft is rare but described in the literature. Prominent screws can lead to dorsal tendon irritation. If the graft is not correct, radial or ulnar instability can occur. If the volar plate fails to heal, hyperextension can occur. The joint can continue to sublux dorsally if the volar buttress is not recreated.

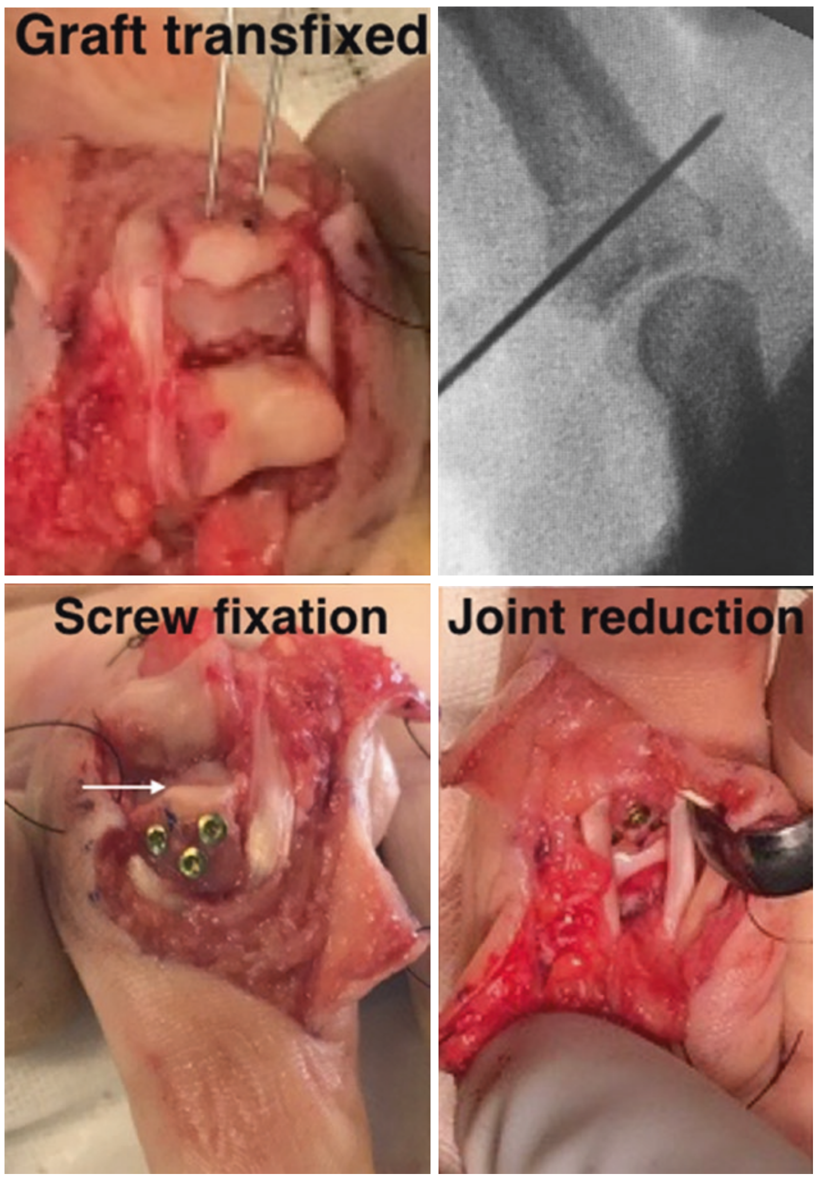

Fig. 2.11 The graft is transfixed with a K-wire when matched appropriately to the defect. This is checked under fluoroscopy. Two to three screws are then introduced (1.2 or 1.3 mm diameter). The joint is reduced and checked for stability. Copyright Dr. Simon MacLean

Fig. 2.12 After fixation, the joint is now reduced and screened under fluoroscopy in full flexion and extension. Copyright Dr. Simon MacLean

2.6 Pilon Fractures

For extensive comminution and pilon fractures, "full-height" hamate grafting can be used. The same technique is used as previously described; however the entire base of the middle phalanx is reconstructed using hamate autograft (Fig. 2.13). In this case, the same volar approach is used, and the base of the middle phalanx is debrided. If the comminution extends to the dorsal cortex, the usual hamate graft will be unsuccessful. Our approach in this situation is to make the graft more extensive, so that it extends from the volar to the dorsal cortex. A volar locking plate is required to provide stability in this situation.

Early range of movement is encouraged, but application of a dorsal blocking splint for 2–3 weeks postoperatively is used to prevent hyperextension.

Other described reconstructive procedures which have been reported include perichondral grafting [30], rib osteochondral grafting [31], and vascularized joint replacement [32, 33].

2.6.1 Volar PIPJ Fracture-Dislocations

These are rarer injuries than their dorsal counterparts. Treatment strategies are similar. Mobilization of the joint is delayed until healing of the central slip occurs. Closed or open reduction is used to reduce the joint. If there is a significant die-punch component with articular depression, a beaver blade can be used to lower the articular surface and graft can be used to fill the void. K-wiring or screw fixation is then performed (Fig. 2.14). Usually the joint is stable in 30° of flexion. The pin can be removed at 4 weeks, followed by full PIP joint rehabilitation. Alternatively, an extension block wire can be used to hold the joint in flexion. This reduces the need for a bulky splint and permits early flexion at the joint [34].

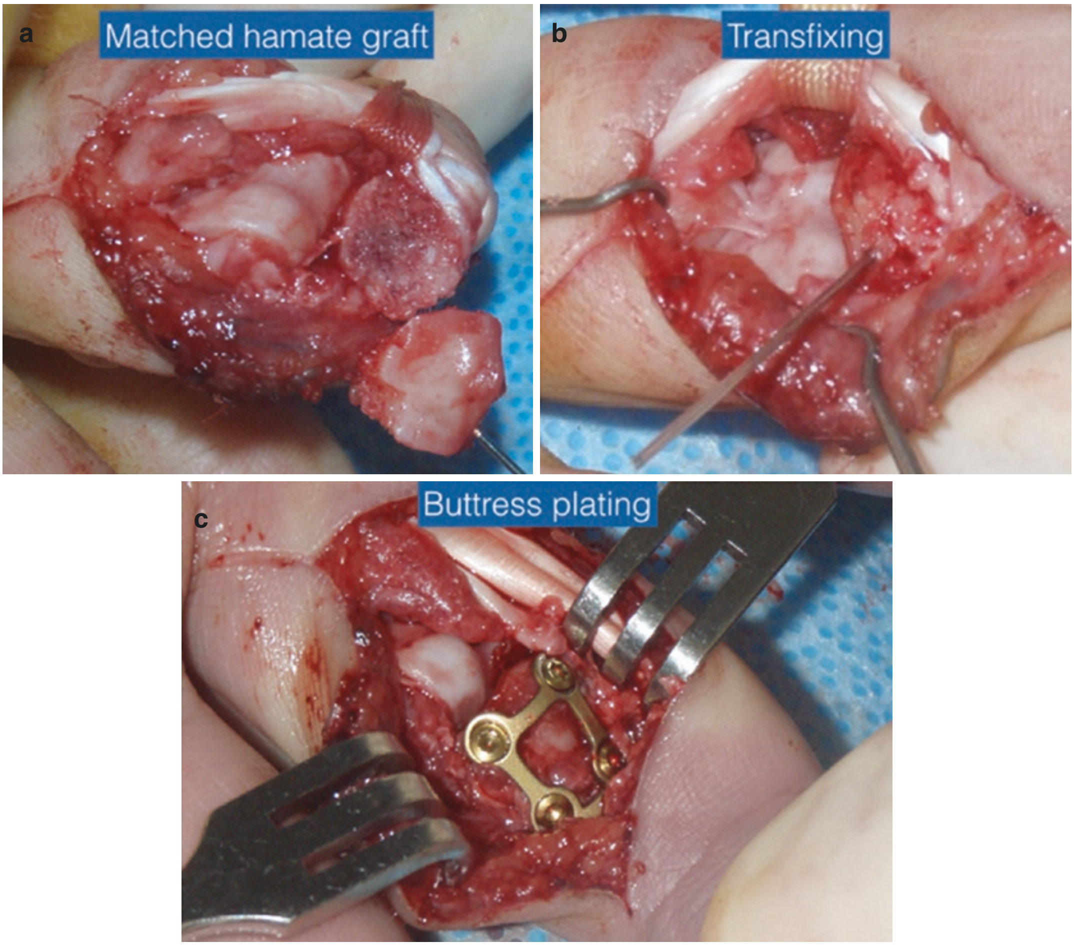

Fig. 2.13 "Full-height" hamate grafting for a complex pilon fracture. (**a**) The hamate graft adjacent to the defect in the base of the middle phalanx. The entire base of the middle phalanx required to be replaced. Unlike the usual hamate graft, there is no dorsal cortex to prevent displacement of the graft. (**b**) Provisional fixation with a transfixing wire. (**c**) Fixation with a small "H" plate, which is required to provide the extra stability, as there is no dorsal buttress for the graft. Copyright Dr. Gregory I. Bain

2.6.2 External Fixation

External fixation for these injuries relies on ligamentotaxis. Fracture reduction can be achieved, and full early range of motion is encouraged. Custom-made frames are cheap to construct, and excellent results have been reported in the literature. There are many techniques that have been published [25, 35–37]. These can be manufactured at the operating table with K-wires and rubber bands (Fig. 2.15).

2.7 Sequelae and Complications

Most patients will develop some degree of stiffness and swelling [7]. Instability and further displacement are rarely an issue. Outcomes are worse in fractures that are highly comminuted, open, or associated with significant soft tissue loss. Early motion is the key in limiting stiffness; therefore any repair or reconstructive strategy should allow for this. Contractures can

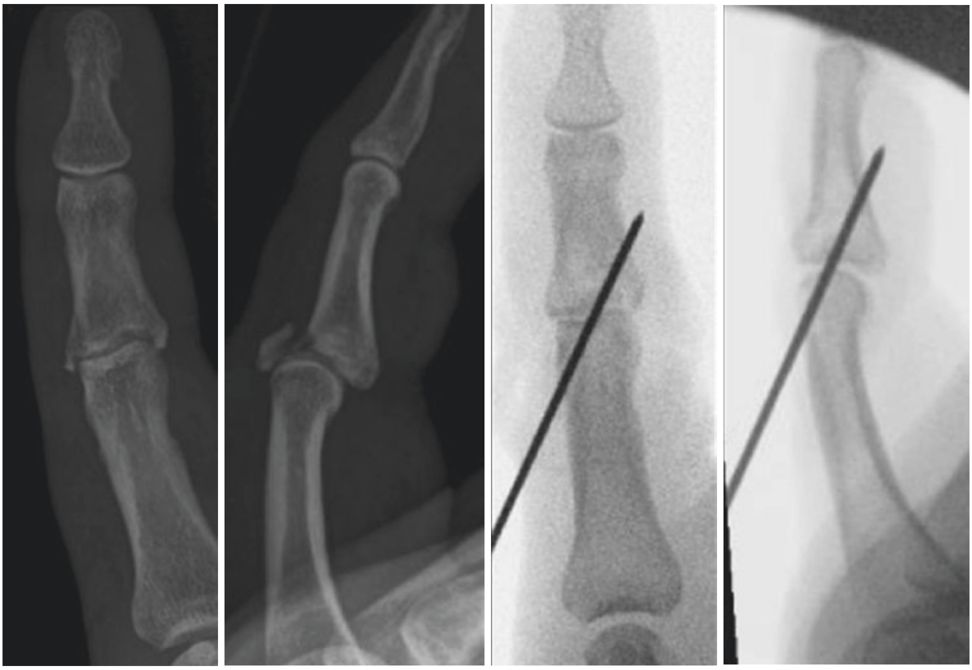

Fig. 2.14 Volar fracture-dislocation of the PIP joint. An open approach was used dorsally between the central slip and lateral band. The fracture had a die-punch component. This was reduced and backfilled with distal radius autograft. The joint was reduced, and a trans-articular wire stabilized the fracture for 4 weeks. Copyright Dr. Simon MacLean

be treated initially by dynamic and resting splints, serial casts, and, in resistant cases, surgical release [9].

Degenerative arthritis is an inevitable outcome if there is joint incongruity or irregularity. Following a volar plate injury, a swan-neck deformity may occur. Boutonniere deformity may develop after central slip injury.

The ideal treatment strategy allows for anatomical reconstruction of the joint surface and early stable range of movement. Clinical and radiographic signs of healing should be evident before a further period of rehabilitation and strengthening. Only at this point can the participant return to combat sports.

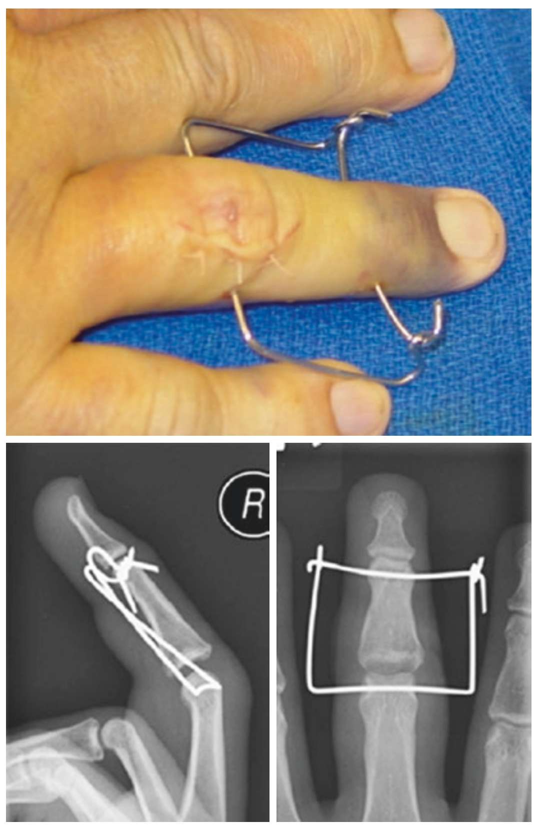

Fig. 2.15 Dynamic external fixator created with K-wires at the operating table. Proximal wire through the center of rotation, within the head of the proximal phalanx. Images courtesy of Dr. Alejandro Badia, Miami

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3 TFCC Lesion in Kendo Player

Toshiyasu Nakamura

3.1 Kendo

In Edo era (seventeenth century to nineteenth century), Kenjutsu using Japanese sword was most popular for samurai (Japanese warrior). In the late eighteenth century, bamboo sword (Shinai) instead of Japanese sword (Shinken) and protectors (men for the head, dou for the body, kote for the hand, wrist, and forearm) for the armors were developed for training purpose of Kenjutsu (that called Shinai training or Gekitetsu). After the revolution of Japan (upset to former Edo Government) in the nineteenth century, every samurai was unarmed, while kendo has been developed as an unique martial arts. Kendo still represents ancient spirits of Japanese samurai, while it is developed in a combat sports activity. Instead of Japanese sword, bamboo sword (Shinai) is now used. Kendo match consists of single match and group competition of five players each (senpo, jiho, chuken, hukusho, taisho). Point is gained by effective hit to the head "men," body "dou," and forearm-wrist-hand "kote." The player who gains two points first is the winner in a match.

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3.2 Upper Extremity Injuries in Kendo

The famous injury in the extremity is rupture of the Achilles tendon, because too much repetitive load was concentrated when the player tries to hit his/her opponent's head/body/forearm. In the upper extremity, lesions in the triangular fibrocartilage complex (TFCC) are popular in kendo players due to repetitive stress applied on the wrist, like other racket sports, such as tennis, golf, or baseball.

Other injuries, such as facture of the finger phalanx or fracture of the forearm bones, are not common in kendo players compared with other combat sports such as judo, karate, or aikido, likely due to the protectors (men, dou, kote).

3.3 Triangular Fibrocartilage Complex (TFCC)

The TFCC is a ligament-fibrocartilage complex that consists of the triangular fibrocartilage (TFC), surrounding ligamentous tissues including the radioulnar ligament (RUL), and sheath floor of the extensor carpi ulnaris (ECU) (Fig. 3.1) [1, 2]. The TFCC stabilizes the ulnocarpal and DRU joints, distributes load between ulna and ulnar carpus, and introduces smooth forearm rotation [1, 2]. When the TFCC is torn, patient usually claims ulnar-sided wrist pain, loss of

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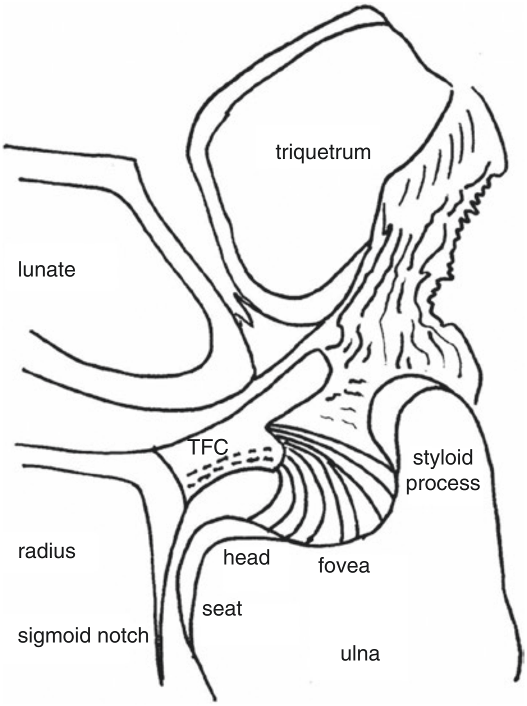

Fig. 3.1 Illustration of the TFCC

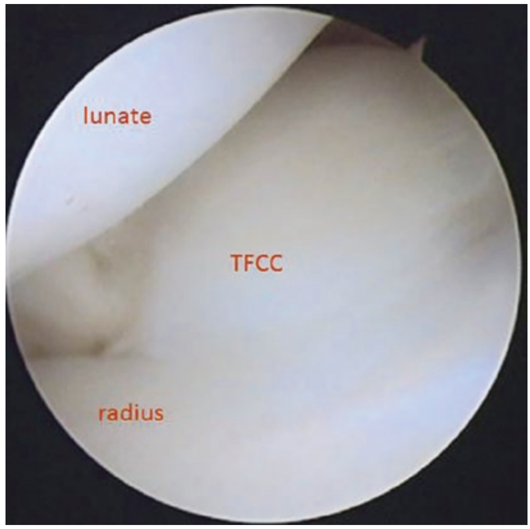

Fig. 3.2 Radiocarpal arthroscopic view of the normal TFCC

Fig. 3.3 Arthrogram of complete avulsion of the TFCC (white arrow) which is classified as Atzei stage 2

forearm rotation, and instability of the DRUJ where they feel slacking on the ulnar head while carrying heavy materials or twisting the door-knob [3]. In kendo, the forearm is forced ulnar-deviated position; when the player applies to hit "men," the ulnar-sided wrist pain appears.

3.4 Classification of TFCC Injuries

Palmer's classification [4] is the most well-known classification of TFCC injuries based upon findings of radiocarpal arthroscopy, which divided TFCC lesion into traumatic (Class 1) and degenerative (Class 2) from radiocarpal arthroscopic findings. Class 1 was subdivided by portion injury occurred as central tear (1A), ulnar tear (1B), distal tear (1C), and radial avulsion (1D). Class 2 was described as the degeneration develops from 2A (wear of the triangular fibrocartilage) to 2E (massive degenerative destruction). Class 1B tear included the peripheral detachment of the disc from the capsule and fracture of the ulnar styloid, even though the radiocarpal arthroscopy can never visualize the ulnar styloid (Fig. 3.2).

Recently, Atzei et al. described their new classification of ulnar tear of the TFCC as stage 1, the distal tear; stage 2, complete tear; stage 3, proximal; stage 4, unrepairable; and stage 5, degenerative [5]. Their distal tear was corresponded to the Palmer 1B ulnar tear, while the proximal tear was the foveal tear, and the complete tear was combination of the proximal and distal tears (Fig. 3.3).

3.5 Diagnosis of TFCC Injuries

The ulnocarpal stress test is effective for assessment of TFCC tear. The fovea sign, tenderness on the palmar side of the base of the ulnar styloid, may suggest the foveal tear [6]. Tenderness of dorsal aspect of the fovea may also indicate the foveal detachment. The most reliable physical test for DRUJ instability is the ballottement test, in which dorsopalmar stability between the ulna and radius is examined in the neutral, pronated, and supinated positions, respectively [7]. When the “end point,” which comes from ligamentous restraint, may be lost, that may demonstrate multidirectional instability of the DRUJ. If the “end point” was noted either in dorsal or palmar direction, partial tear of the RUL may exist. Piano key sign, indicating the floating ulnar head in the pronation position, may also helpful to diagnose the fovea avulsion.

MRI can demonstrate TFCC tear including foveal detachment clearly (Fig. 3.4). Gradient echo sequence T2*-weighted image and fat suppression T1-weighted image delineate detailed TFCC structure well [8]. Arthrogram still has advantage to delineate slit tear on the TFC. In foveal detachment of the TFCC, arthrogram also shows pooling of the dye at the fovea, inclusion of the dye between the TFCC and ulnar fovea (Fig. 3.3), or dye infiltration into the proximal side of the TFCC.

Fig. 3.4 T2*-weighted MRI indicates fovea avulsion of the TFCC (white arrow)

3.6 Treatment of TFCC Injury in Kendo

There are several treatment options for TFCC injury in kendo player. Normally, conservative treatment, such as supporter, cast immobilization, or taping on the DRUJ, is firstly applied for 3 months after the initial injury. If the conservative treatment fails, surgical treatment should be considered.

3.6.1 Arthroscopic Partial Resection of the TFCC

Arthroscopic partial resection of the TFCC was widely indicated to TFCC injury in the 1990s. The indication of arthroscopic partial resection is now limited to Palmer 1A or 1D tear without any DRUJ instability. Other indication of arthroscopic partial resection of the TFCC is blockage of forearm rotation due to entrapment of the flap tear of the disc into the DRUJ. Minimal resection of tear site on the fibrocartilage is recommended not to introduce

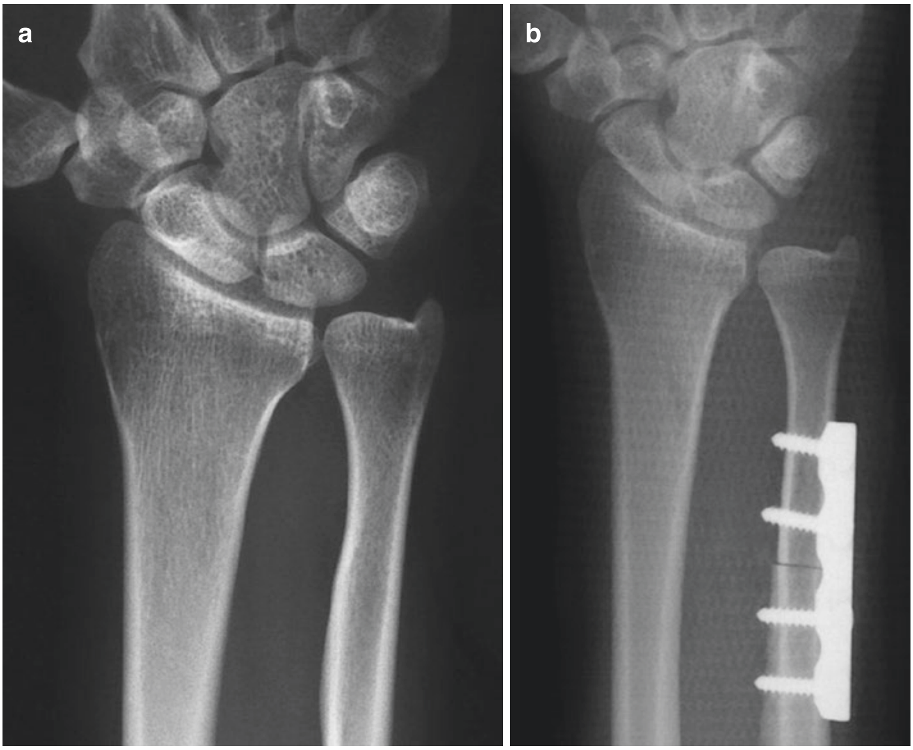

Fig. 3.5 (**a**) Pre-operative PA radiograph indicating positive ulnar variance. (**b**) postoperative PA radiograph after ulnar shortening

DRUJ instability, because the RUL is just proximal to the TFC. Arthroscopic partial resection indicates faster pain relief and recovery to kendo. If there are degenerative findings or DRUJ instability with manual ballottement test, arthroscopic resection of the TFCC results in failure.

3.6.2 Ulnar Shortening

Ulnar shortening is normally indicated to the ulnar-positive variance wrist where the ulnar is relatively longer to the radius on plain radiographs (Fig. 3.5). Ulnar shortening obtained favorable clinical results. Ulnar shaft is at its middle part cut by an appropriate length horizontally, obliquely, or in step cut, and the plate is applied to fix the ulna. The ulnar shortening decreases pressure between the ulna and ulnar carpus [9] and increases stability of the DRUJ [10]. Thus, the ulnar shortening procedure can also be performed with mild to moderate DRUJ instability that is due to partial RUL tear in the ulnar neutral variance wrist. When the RUL was completely torn, the ulnar shortening can no longer stabilize the DRUJ. The ulnar shortening procedure has also demerit to decreasing DRUJ congruity with increasing DRUJ pressure that may induce osteoarthritic changes on the DRUJ [11].

The metaphyseal ulnar shortening technique using the headless compression screw or hooked plate was described with an advantage for shorter union period [12–14] (Fig. 3.6).

3.6.3 Arthroscopic Capsular Repair

When the TFCC is torn peripherally (Palmer Class 1B [4] or Atzei stage 1 [5]) while the RUL still attaches to the fovea lesion, arthroscopic capsular repair obtained excellent clinical results [12, 13]. There are several techniques including outside in (Fig. 3.7) [12, 13], inside out, or all inside [14]. Even in chronic cases, debridement using shaver can refresh the tear site of peripheral lesion at the TFC, and arthroscopic repair is possible.

Fig. 3.6 Pre and postoperative radiographs of the metaphyseal ulnar shortening technique

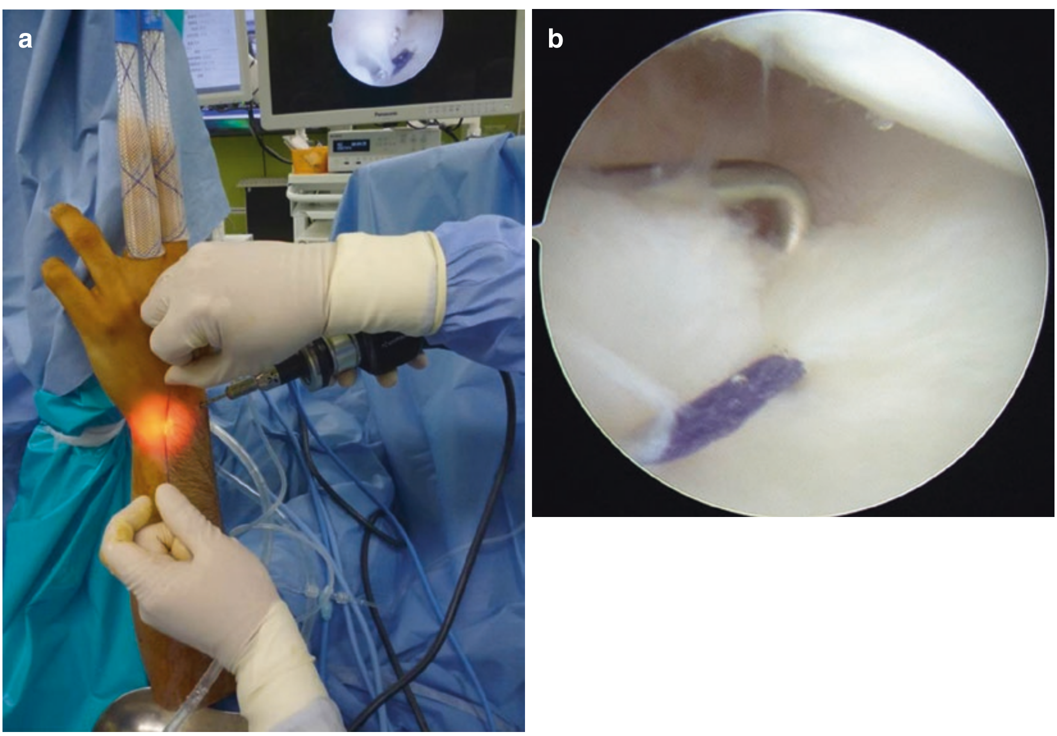

Fig. 3.7 (**a**) Intraoperative view of arthroscopic outside-in capsular suturing technique. (**b**) Radiocarpal arthroscopic view of arthroscopic capsular repair for 1B peripheral TFCC tear

3.6.4 Arthroscopic Transosseous TFCC Repair

When the TFCC was avulsed from the fovea (Atzei stages 2 and 3 [5]) within 6 months after the injury, arthroscopic transosseous repair can be indicated [3, 15, 16]. The foveal area is debrided by a small shaver inserted from the DRUJ ulnar portal after foveal detachment of the TFCC is confirmed by DRUJ arthroscopy [3]. The "Wrist Drill Guide" (Fig. 3.8; Arthrex, Munich, Germany) is set on the ulnar half of the TFC. Two parallel small holes are made from the ulnar cortex with a 1.5-mm K-wire. Outside-in pullout suture technique reattaches the avulse RUL with the TFC to the fovea using nonabsorbable 3-0 polyester sutures (Ticron, Covidien, Mansfield, MA) (Fig. 3.9). The suture anchor is also used to reattach the RUL to the ulnar fovea [15].

Fig. 3.8 Drill-guide setting in arthroscopic transosseous repair technique of the TFCC

3.6.5 TFCC Open Repair

The TFCC can be repaired in an open fashion through the fifth or sixth extensor compartment [3, 17]. The condition of the RUL fibers can be assessed by pulling the distal remnant with the forceps to determine whether it can be sutured. The fovea region is debrided of scar tissue, and two small holes are made with a 1.2-mm K-wire, as close to the center of the fovea as possible. The disrupted RUL is sutured with a double three-dimensional mattress suture technique through these two tunnels (Fig. 3.10). When the fifth compartment was opened, the dorsal area of the TFC should be repaired.

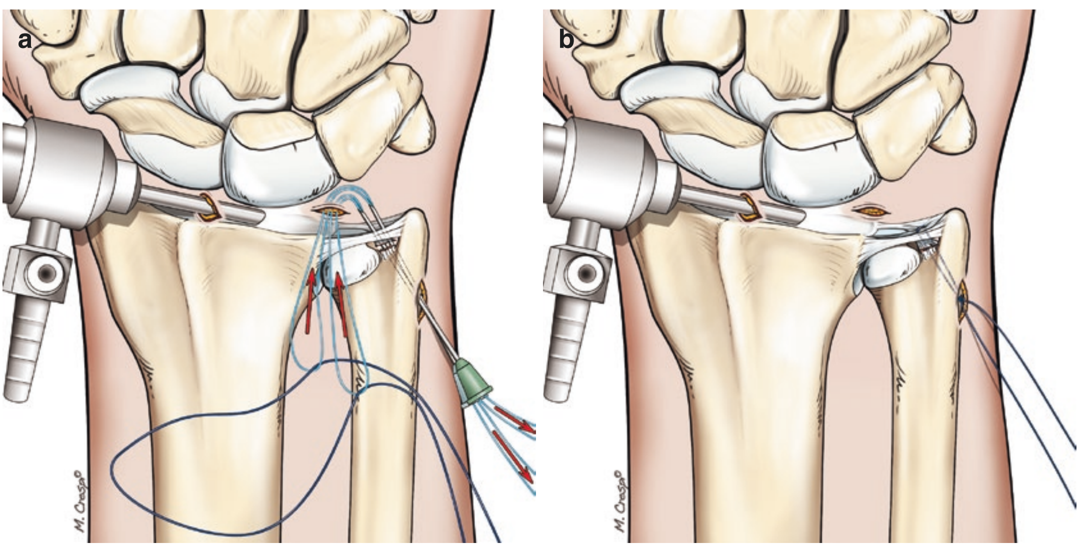

Fig. 3.9 (**a**) Illustration of arthroscopic transosseous repair technique of the TFCC. Main stitch is introduced by loops set in the 21G needles that was passed through the parallel holes. (**b**) Illustration of arthroscopic transosseous repair. Avulsed TFCC is tightly anchored by the stitch

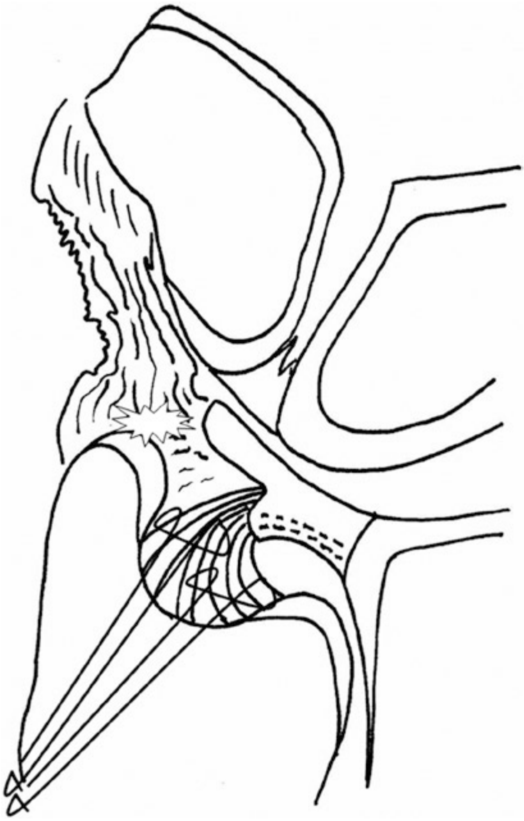

Fig. 3.10 Illustration of open repair technique of the TFCC

Fig. 3.11 Radiograph of the reconstruction of the TFCC to the ulnar fovea using an ECU half-slip tendon

3.6.6 TFCC Reconstruction Using the ECU Half-Slip Tendon

In a chronic (at least 6 months after the initial injury) or a severely or completely damaged TFCC condition, the author recommends reattachment technique of the TFCC to the ulnar fovea using an ECU half-slip tendon with the interference screw [18–20]. The technique described is suited for wrists with the neutral or minus ulnar variance. Ulnar shortening is performed in wrists with a positive variance to be equalized to the neutral variance before reattachment. One bone tunnel is made with a 2.5-mm diameter drill from the center of the fovea to the ulnar cortex. The position of the bone tunnel at the fovea is as close to the center of the fovea as possible, which serves as an isometric point on the ulna during forearm rotation [21]. The distally based ECU half-slip tendon is harvested and then introduced into the TFCC from this distal small incision made at the radiocarpal joint level, passing through the TFCC, and attached to the DRUJ surface at the fovea. The ECU half-slip was subsequently anchored to the ulnar fovea with a small titanium interference screw to reattach the TFCC (Fig. 3.11).

When the TFCC was disrupted completely, PL tendon reconstruction should be considered. Adams and Berger described anatomical reconstruction of the TFCC using PL tendon to reconstruct dorsal and palmar portions of the RUL [22].

3.7 Case Series

From 2001 to 2015, 13 kendo players underwent surgical treatment of TFCC injuries in our institute. There were 11 males and 2 females with an average age of 21 (range 15 to 48). Three right and ten left wrists were involved. Three patients were junior high school students, seven were high school students, one was a university student, and two were teachers. Obvious causes were unknown in all patients, while all claimed difficulties to play kendo due to ulnar-sided wrist pain. Diagnosis of TFCC injury was done by MRI and arthrogram and confirmed with wrist arthroscopy.

Arthroscopic exploration revealed that there were Palmer 1B tear in one wrist, complete rupture of the TFCC at the fovea in seven, Palmer 2A tear in four, and 2C in one. Associated injuries were nonunion of the ulnar styloid in three, rupture of the extensor carpi ulnaris (ECU) tendon sheath floor in one, and complete rupture of the ECU tendon in one.

Arthroscopic capsular repair was selected for 1B tear, open repair in five, arthroscopic transosseous repair in one, and reconstruction of the TFCC using an ECU half-slip tendon in one. Five cases of degenerative TFCC injury cases and three cases of positive ulnar variance cases were treated with ulnar shortening. For associated injuries, fixation of the ulnar styloid fragment was selected in one wrist, while in other two wrists removal of the fragment was performed. Tendon sheath floor of the ECU was repaired, and tenodesis of the ECU tendon was selected in complete ruptured case. Clinical outcome obtained was 12 excellent and 1 good, all returned to original sports level.

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4 Hand and Wrist Injuries in Karate

Keiji Fujio

4.1 Wrist Injuries

4.1.1 Triangular Fibrocartilage Complex and Scapholunate Injuries

For karate practitioners, it is easy to suffer a triangular fibrocartilage complex (TFCC) or scapholunate (SL) ligament injury during self-defense (*Ukemi*), which involves a wrist extension position and absorption of the opponent's power. Of the top athletes operated on in our hand clinic from 2009 to 2012, 4 of the 58 who suffered a TFCC injury and 3 of the 24 who suffered a SL injury were karate practitioners.

4.1.1.1 Triangular Fibrocartilage Complex Injury

The patient usually complains of ulnar wrist pain and difficulty of wrist rotation. For diagnosis, distal radioulnar joint (DRUJ) stability should be assessed with the fovea sign [1] and an instability test. A positive ulnar fovea sign may indicate foveal disruption or ulnotriquetral ligament injury. DRUJ instability is assessed by passive anteroposterior translation of the distal ulna to distal radius in neutral rotation, supination, and pronation when the forearm muscles are fully relaxed in comparison with the contralateral side. Ulnar variance should be checked on an X-P x-ray. Coronal T2 star magnetic resonance imaging (MRI), with scout views of a helical view centering around the fovea (Fig. 4.1) and a horizontal view parallel to the ulnar head diameter passing by the ulnar styloid (Fig. 4.2), is useful for evaluation of TFCC foveal insertion (Fig. 4.3).

Conservative treatment should be applied immediately after the injury. We recommend application of a sugar-tong-type cast for 3 weeks and a TFCC brace (Fig. 4.4) for the next 3 weeks.

If conservative treatment fails, TFCC repair should be applied. Cases neglected for a long duration can be repaired within 1 year with an arthroscopic transosseous technique.

Our indications for operation are:

1. Pain or clicking during pronation and supination
2. Positive sign of instability, positive fovea sign, or a positive ulnocarpal stress test
3. Confirmed avulsion of the TFCC at its ulnar insertion on MRI and DRUJ arthrography.

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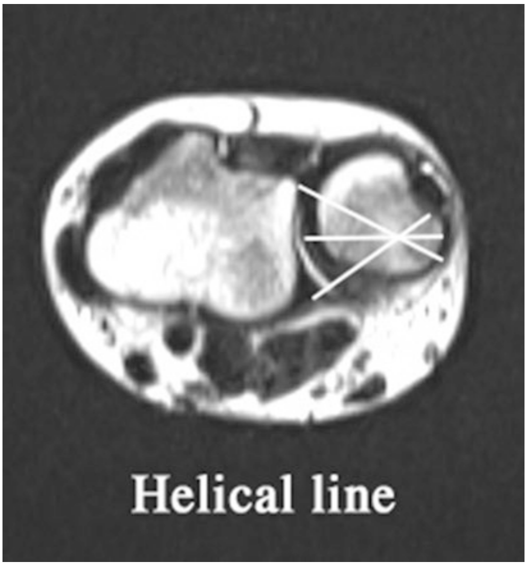

Fig. 4.1 Magnetic resonance imaging scouted by the helical line

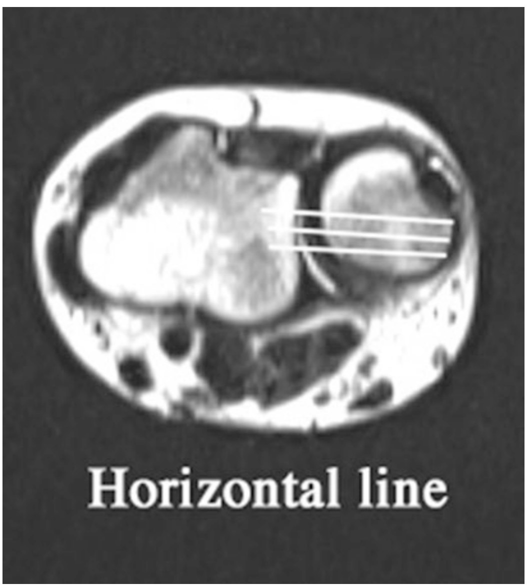

Fig. 4.2 Magnetic resonance imaging scouted by the horizontal line

Fig. 4.3 Magnetic resonance imaging shows high density around the fovea

Fig. 4.4 Triangular fibrocartilage complex (TFCC) brace

Our surgical technique includes three steps:

1. *Diagnosis from the radiocarpal joint (RCJ): trampoline test, hook test, and floating sign from the RCJ*. A wrist arthroscope is inserted using the 3–4 portal for exploration to locate the TFCC tear. A probe is inserted via the 4–5 portal. The articular disk is then examined by the probe with the so-called trampoline test [2] and the hook test [3]. Hermansdorfer and Kleinman [4] showed that the trampoline effect may reveal diminished tension on the horizontal disk, suggestive of an ulnar TFCC detachment. In my opinion, the floating sign [5] (Fig. 4.5), which is a sign in which the TFCC around the fovea is floating during

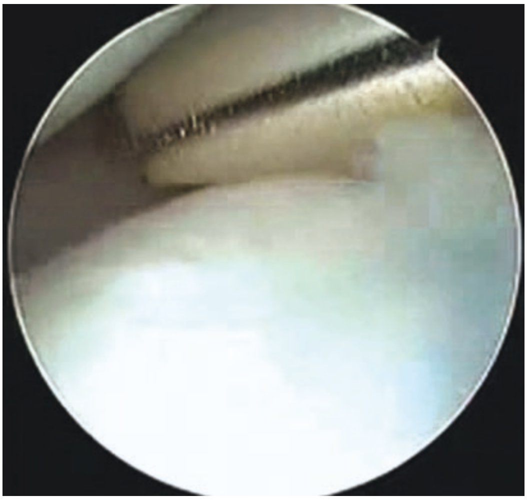

Fig. 4.5 Floating sign

Fig. 4.6 Debridement of the fovea from the ulnar distal radioulnar joint (DRUJ-U) portal, seen from the radial distal radioulnar joint (DRUJ-R) portal

suction with a shaver, is usually helpful to make a decision on foveal detachment from the radiocarpal joint if there is perforation connecting between the RCJ and the DRUJ like Palmer 1A. Next the torn TFCC is checked from the DRUJ scope directly. From the radial DRUJ portal, the scope is inserted with probing from the ulnar DRUJ portal.

2. *Foveal debridement*. Foveal debridement is an important procedure for subacute or chronic cases to produce a good healing potential that allows bone-to-tendon reattachment.

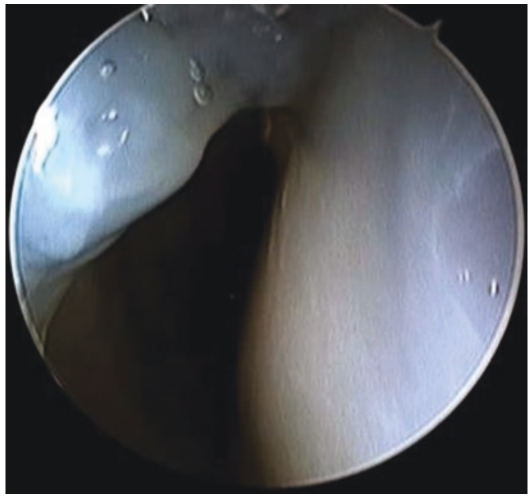

Fig. 4.7 Video of debridement around the fovea

Fig. 4.8 Instrument for inside-out suturing

Debridement is performed from the ulnar DRUJ portal with a shaver (Figs. 4.6 and 4.7).

The TFCC remnant should be debrided, preserving as much of the real ligament tissue as possible. For the foveal side, the remnant is debrided more aggressively for exploration of the foveal cortex.

3. *Inside-out technique*. A 2-cm skin incision is made on the volar proximal ulnar styloid. The superficial ulnar nerve is reflected meticulously, the retinaculum is incised sharply, and the ulnar cortex is explored. To repair an ulnar-sided TFCC tear, a single-lumen curved guide (Fig. 4.8) is inserted through the 4–5 portal, targeting the fovea. The curve at the tip of the cannula makes targeting of the fovea more accurate. In 1993, Bade [6] reported the relationship between the recess and the fovea.

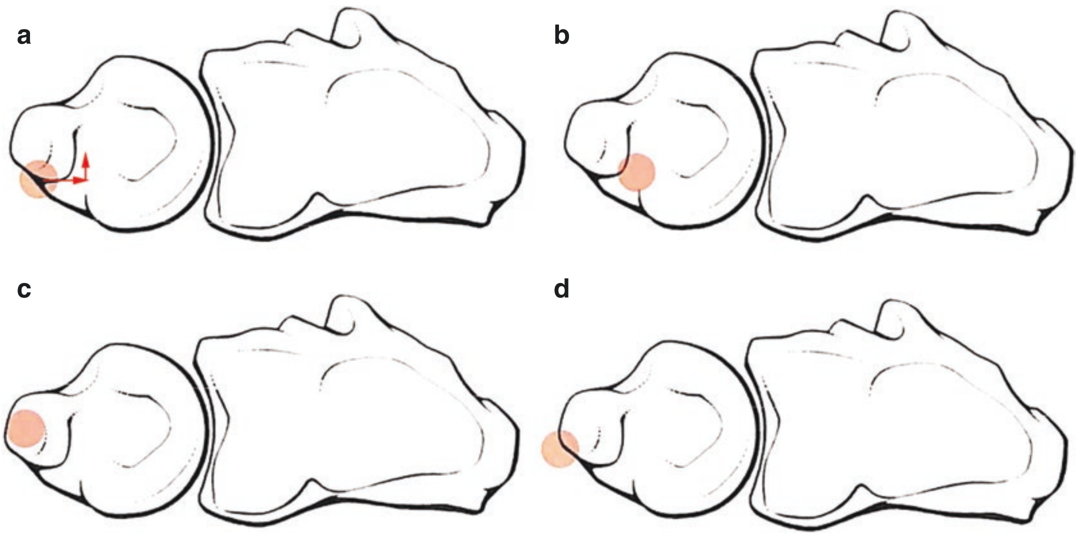

Fig. 4.9 Relationship between the fovea and recess: type a is more frequent

Fig. 4.10 Suture knots on the ulnar cortex

An appropriate entry point for the isometric point would be just dorsal with radial recess viewing from the RCJ (Fig. 4.9). A neutral, slightly supinated position allows easy placement of the needle using a curved guide in the center of the fovea because the ulnar styloid moves to a more volar position.

The stitcher needle (a soft wire 1.0 mm in diameter, made by Smith & Nephew), which has a hole on the end of the needle, is drilled via the curved guide through the ulnar TFCC and the distal ulna bone, and comes out on the ulnar aspect of the ulnar cortex. We then run a thread 2-0 fiber wire to the hole and pull the needle, using an oscillating technique (Fig. 4.10). This maneuver is repeated for the other side of the thread. Usually two knots around the isometric point are made.

After traction release, two sutures are tied on the ulnar cortex separately. For the postoperative protocol, plaster with the arm in a neutral position is applied for 3 weeks. Active motion is started after removal of the plaster. Passive motion is started 6 weeks after the operation.

4.1.1.2 Scapholunate (SL) Injury (Predynamic Stage)

Some karate practitioners complain of dorsal wrist pain during push-ups and power grips without X-ray and MRI evidence. They are sometimes misdiagnosed for a long time.

Our method is to make shrinkage the proximal SL redundancy from the RCJ, and the Radioscaphocapitate ligament from the midcarpal joint with radiofrequency (RF). All cases have improved from Geissler stage 3 to stage 2.

A few karate practitioners suffer a static SL injury, which should be reconstructed by some varieties of the method. Bone-to-bone, flexor carpi radialis (FCR) reconstruction, arthroscopic palmaris longus (PL) reconstruction, and dorsal intercarpal (DIC) translation, etc., have been reported. It is important to maintain a primary internal stabilizer such as Kirschner fixation, a double-thread screw as in reduction and association of the scaphoid and lunate (RASL), and the SwiveLock system for any ligament reconstructions. Recently the SwiveLock system has been developed as a primary stabilizer.

4.2 Finger Injuries

4.2.1 Mallet Finger With or Without Fracture

If there is no fracture, immobilization with a continuous splint for 6 weeks is recommended (Fig. 4.11). The result with a continuous splint is almost the same as that achieved by operative management such as suture repair [7]. Both approaches result in a slight extension lag under 5°, and conservative treatment results in no extension contracture in comparison with operative treatment.

If there is a fracture (Fig. 4.12), we recommend Ishiguro's method [8] with two Kirschner wires. One is for a block against fragments, and the second is to reduce and fix the dislocated distal interphalangeal (DIP) joint (Fig. 4.13). It is important to reduce volar dislocation of the distal phalanx at the DIP joint.

4.2.2 Extensor Retinaculum Graft for Chronic Karate Knuckle

Karate knuckle is a capsular rupture caused by a direct blow to the dorsal side of the metacarpophalangeal (MP) joint in which no abnormalities are apparent radiographically. It often is associated with sagittal band rupture. Several studies

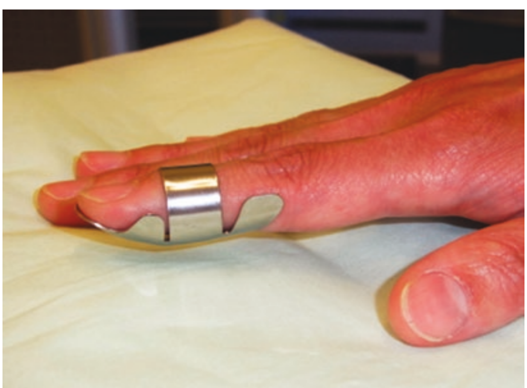

Fig. 4.11 Brace for mallet finger without fracture

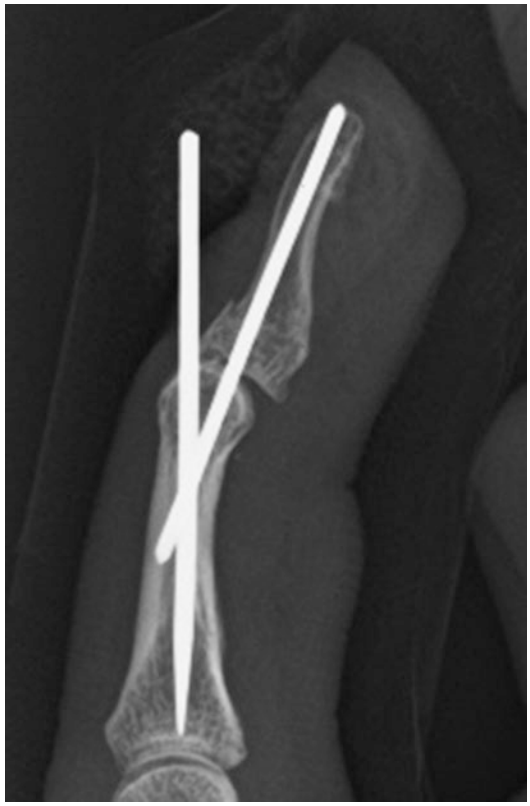

Fig. 4.12 X-ray lateral view of bony mallet finger with two Kirschner wires

Fig. 4.13 Reduction and fixation with Ishiguro's method

[9–11] have been conducted since Gladden [12] first documented this condition in 1957. Karate knuckle causes pain when punching, which is why surgery is indicated for boxers and karate practitioners. Koniuch et al. [10] reported that 9 of 11 patients had chronic pain and swelling without extensor tendon subluxation for an average of 7.4 months, and on exploratory surgery had a consistent anatomic lesion that consisted of a partial arcuate tear of the sagittal fibers. All of the patients improved postoperatively.

Nagaoka et al. [13] reported five cases of chronic boxer and karate knuckle in which capsular repair could have impaired MP joint flexion; the scar tissue of the damaged capsule and the sagittal band were removed and an oval extensor retinaculum graft was sutured in the capsule and sagittal band defect (Fig. 4.14). All five patients were able to return to professional competition.

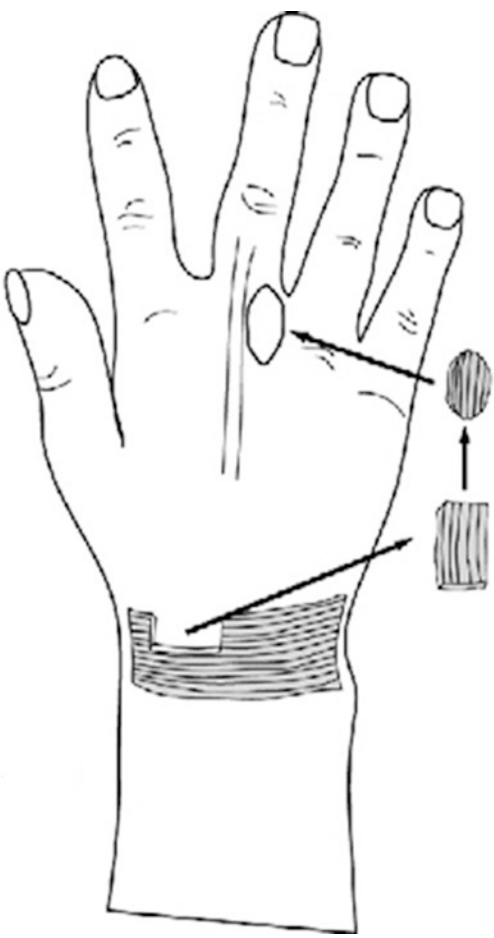

Fig. 4.14 Extensor retinaculum reconstruction

4.2.3 Metacarpal Head Fracture

Metacarpal head fracture is very common in karate when using a fist position. When the displacement or malrotation is acceptable, conservative treatment with a removable cast with metacarpophalangeal (MP) flexion and proximal interphalangeal (PIP) free is recommended. MP extension immobilization is contraindicated because the MP can easily result in an extension contracture. If angulation and malrotation at the fracture site are too excessive (Fig. 4.15), retrograde intramedullary pinning (Fig. 4.16) is recommended. Sometimes the width of the intramedullary bone is narrow, and a single Kirschner wire (1.5 mm) is acceptable. Ideally a double Kirschner wire is desirable. It is convenient to use the tip of the Kirschner wire, which is bent and made to curve at the middle shaft. Postoperatively a removable cast is applied with MP flexion and PIP free for 3 weeks.

Fig. 4.15 Preoperative metacarpal fracture

Fig. 4.16 Intramedullary fixation

Fig. 4.17 Necrosis of the metacarpal head

4.2.4 Metacarpal Head Necrosis

Aseptic necrosis of the metacarpal head is an extremely rare condition known as Dieterich's disease [14] with systemic lupus erythematosus, steroid use, trauma, and bone infarction at other sites. We experienced a case of it in a 16-year-old male karate practitioner who suffered an index proximal phalanx base fracture. He was immobilized with plaster and had a united fragment 6 weeks after the injury. He consulted our clinic 3 months after the injury, complaining of pain, a restricted range of movement (ROM), and swelling on the MP joint. X-P revealed flattening of the metacarpal head. Subcortical bone resorption was visible (Fig. 4.17). Arthroscopic synovectomy, debridement of cartilage debris, and subchondral drilling were performed. The MP was mobilized with flexion for 3 weeks. Active ROM was then started, and passive ROM was started 6 weeks after the operation. An x-ray 3 months after the operation revealed that the extent of necrosis was diminished (Fig. 4.18). He returned to his previous level of karate practice 6 months after the operation.

Fig. 4.18 Three months after synovectomy and drilling arthroscopically

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5 Grip Injuries in Judo: Flexor Tendon Avulsion

Eduardo Pereira, Laura Filippini Lorimier Fernandes, and Luciano Pereira

5.1 Introduction

Judo is a martial art and an Olympic sport combining standing and ground fighting and basically consists of grabbing and throwing the opponent on the floor [1]. Nowadays, judo ranks among the most popular martial arts in the world with an estimated 20 million fighters affiliated to the International Judo Federation [2, 3]. An injury data from the Olympics of 2008 and 2012 revealed an average injury risk (the number of injured athletes divided by the number of athletes at risk [4]) of 11.2–12.3% [5, 6].

In judo, one objective is to get the first grip possible. It gives the power to dictate the direction of play. When you pull, the opponent reacts and pulls in other direction trying to release, so hands are at high risk, up to 30% [7], during grip fighting "Kumikata" (Fig. 5.1) [8, 9].

5.2 Mechanism of Injury

The finger injuries are commonly dislocations or sprains of the interphalangeal joints, mostly due to a wrong grip (Fig. 5.2) with the fingers blocked in the swell of the judogi (kimono) [1]. One of the most severe injuries on judokas' fingers related to grip fighting is the avulsion of the flexor digitorum profundus tendon.

Since 2010, it is not permitted to grab the legs (Fig. 5.3) or trousers, initially, during tachi-waza (standing techniques) [3]. It was a big problem due to the difference of power between the leg and fingers (personal note of Dr. Riccardo Luchetti – hand surgeon and judoka).

This injury is most commonly seen in the ring finger because of its weaker insertion of flexor profundus tendon [10] and because of its position as the most prominent finger when all the fingers are partially flexed [11]. It is caused by the athlete grabbing the opponent's clothing and was first described in rugby players, and it's usually called *jersey finger* (Fig. 5.4). The distal phalanx is forced extended against maximally contracted flexion force [12].

5.3 Physical Examination

The patient often feels a "snap," and the finger assumes a position of extension when compared to the other digits, disrupting the cascade of the fingers [13].

At the examination, there is an inability to actively flex the DIP joint, which is the pathognomonic finding of jersey finger; it also might be swollen and painful at palpation of the volar

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Fig. 5.1 Kumitaka

Fig. 5.2 Grip techniques in judo—above, right grips; below, wrong grips

surface from the distal palmar crease to the DIP joint; the point of maximal tenderness along the finger may represent the stump of the retracted avulsed tendon (Fig. 5.5).

To examine the integrity of the tendon, the clinician holds the proximal interphalangeal (PIP) joint in full extension and asks the patient to flex the DIP joint [14]. Alternatively, the clinician can ask the patient to make a fist [15]. As part of the complete examination of an injured digit, the clinician should assess the finger's neurovascular function and inspect the soft tissue for lacerations and nailbed injuries. If a thoughtful examination and suspicion is not made early, it might be misdiagnosed initially as a "sprained finger" worsening the prognosis of the lesion [16].

Fig. 5.3 High-risk grabbing

5.4 Imaging

Radiographic examination of the affected finger should be performed in anteroposterior and lateral views to evaluate if it was just a tendon avulsion or if there is an associated avulsion fracture of the distal phalanx.

Although it is operator dependent, ultrasound can be used to evaluate jersey finger [17]. An MRI should be considered in high-performance athletes, if the diagnosis remains doubtful or the location of the retracted tendon is unclear. It can also be helpful in the evaluation of chronic injuries. MRI accurately depicted the location of tendon rupture and the gap between tendon ends as subsequently determined during surgery [18] (Fig. 5.6).

5.5 Classification

These avulsion injuries were first classified in 1977 by Leddy and Packer into three types [12]:

Fig. 5.4 (**a**) Rugby player grabbing opponent's jersey, (**b**) judoka grabbing opponent's judogi

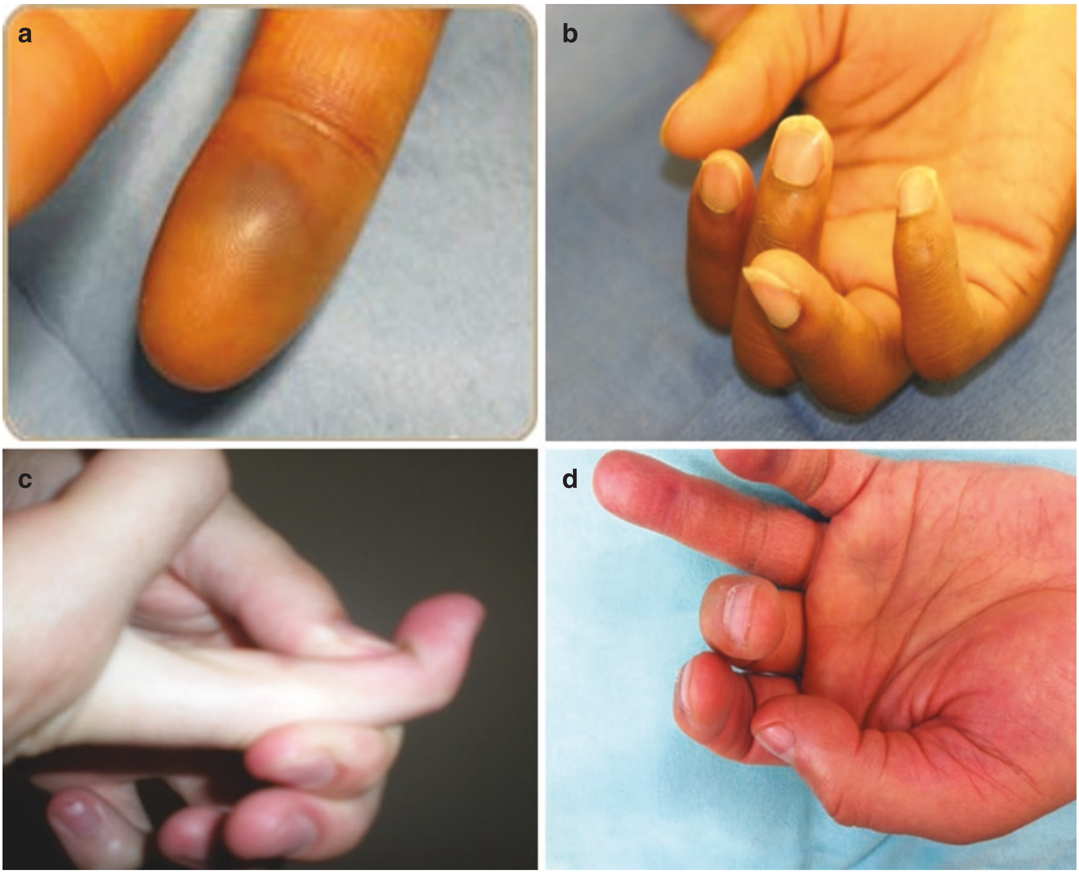

Fig. 5.5 Physical examination of FDP avulsion; (**a**) swelling at volar aspect of DIP; (**b**) disruption of flexion cascade; (**c**) FDP maneuver test; (**d**) hematoma at palm level

- Type I (Fig. 5.7) avulsions at the insertion–distal phalanx, in which the proximal tendon has retracted into the palm.
  - No bone fragment.
  - Tendon is held up by the lumbrical origin.
  - Vincular arteries are ruptured.
  - Repair must be done within 10 days; otherwise the tendon will become necrotic.
- Type II (Fig. 5.8) injuries occur as the avulsed tendon with a small bone fragment retracts to the level of PIP joint.
  - The small bone fleck is not easily seen on X-ray.
  - The bone fragment gets caught at the bifurcation of FDS tendon.
  - Long vincular artery remains intact.
  - There is no necrosis or tendon contracture.
  - There is no tenderness point in the palm.
  - Surgical repair can be done as late as 3 months.
- Type III (Fig. 5.9) injuries involve avulsion of the tendon with a larger piece of bone from the base of distal phalanx that gets caught at the level of the A4 pulley.
  - There is no retraction past the DIP joint.
  - There is no vascular injury.

5.6 Treatment

Acutely, the injured finger should be immobilized (placed in a splint with the PIP and DIP joints slightly flexed). The splint provides support and prevents extension of the DIP joint. Definitive

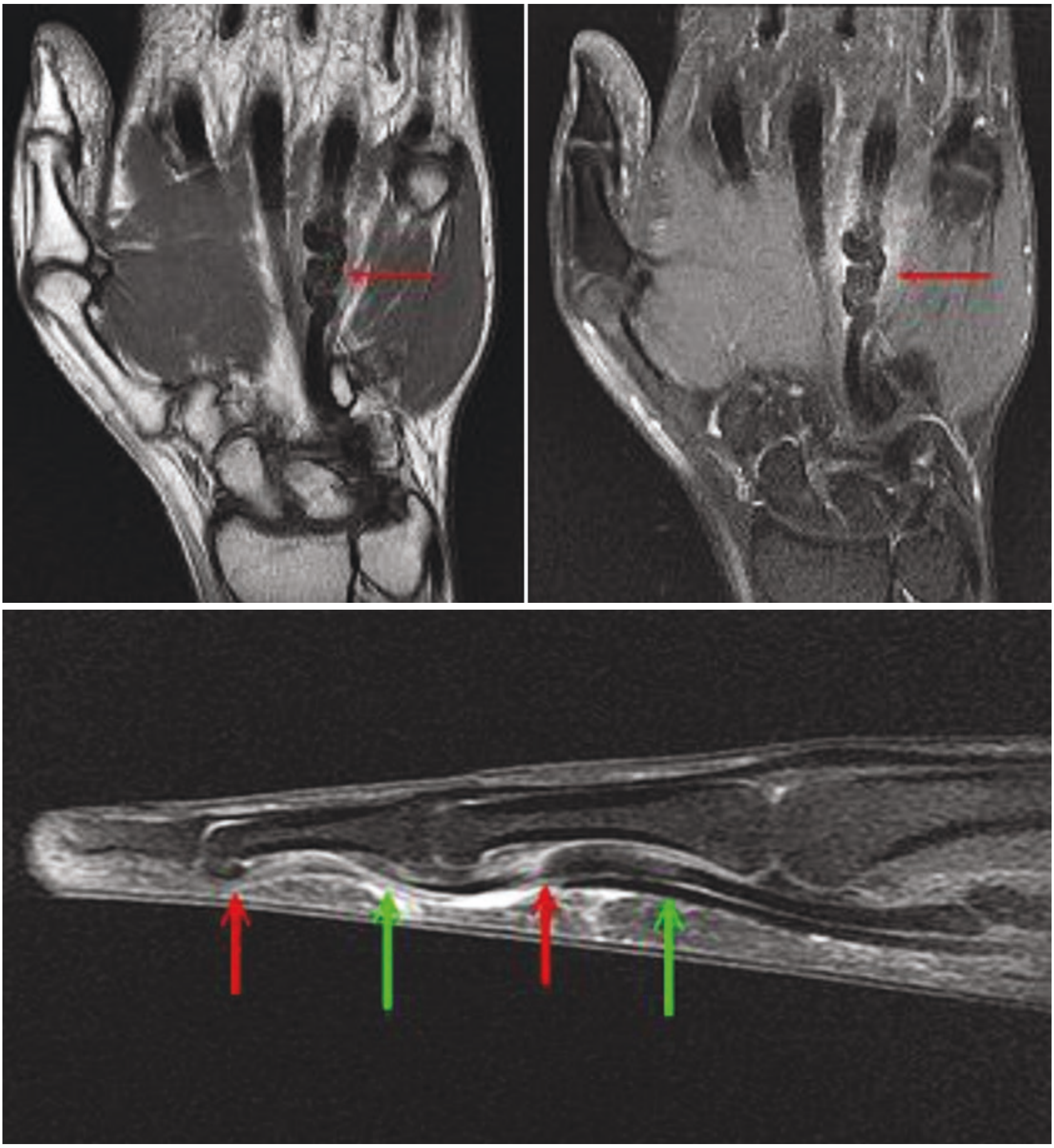

Fig. 5.6 MRI of FDP avulsion

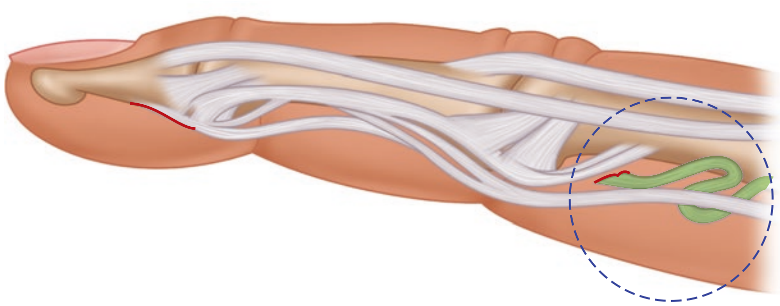

Fig. 5.7 Leddy and Packer type I

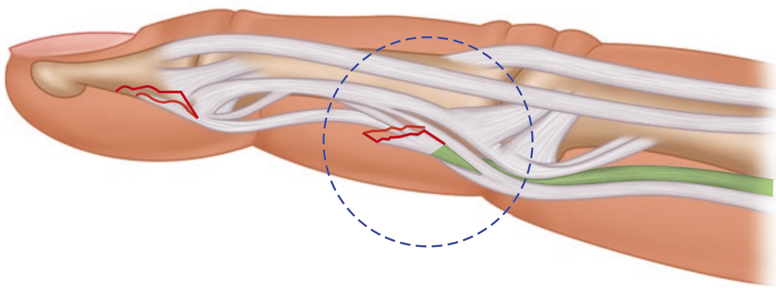

Fig. 5.8 Leddy and Packer type II

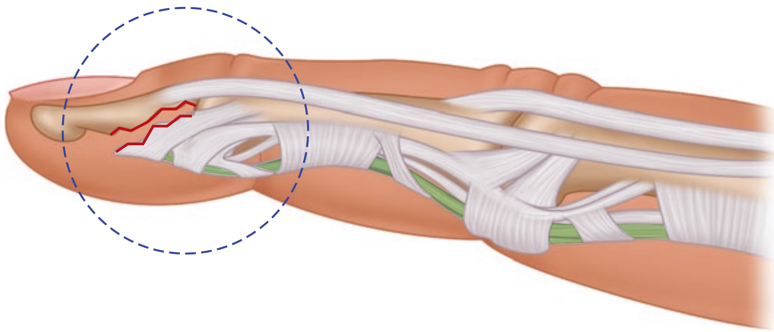

Fig. 5.9 Leddy and Packer type III

treatment of jersey finger injuries always requires surgical repair [16].

5.6.1 Type I

Type I injuries represent avulsions in which the proximal tendon stump has retracted into the palm. These must be treated in an urgent fashion to avoid degeneration of the tendon and myostatic contracture. The rapid degeneration occurs because of the lesion to both vincula, leaving the tendon with almost no vascular supply. The resulting hematoma in the flexor sheath also contributes to the risk for scar formation and contracture, hence the need for urgent repair [13].

The diagnosis often is delayed because the finger still can flex at the metacarpal–phalangeal (MCP) joint by the action of intrinsic muscles and at proximal interphalangeal (PIP) joints because of the action of the flexor digitorum superficialis (FDS) tendons.

The tendon should be reinserted up to 10 days before the tendon becomes necrotic and contracted. Normally the tendon stump retracts to distal palmar crease, so the surgeon must make a palm incision. The second step is to retrieve the tendon through the pulley tunnel. It can be done with the aid of nasogastric tube. The next step is to fix the tendon back to the bone. It can be done using several techniques (the pullout wire and button technique, mini-anchor, transosseous suture). Care must be taken not to injure the volar plate of the distal interphalangeal joint, an injury which can result in a flexion contracture [12] (Fig. 5.10).

Treatment options after a delay in diagnosis include DIP fusion, reconstruction of the FDP, no treatment, or excision of the profundus if it becomes a painful nodule after retracting into the palm.

The FDP can be reconstructed in a one-stage procedure with the graft placed around rather than through the FDS decussation [19]. The loss of DIP flexion is not severely disabling; however,

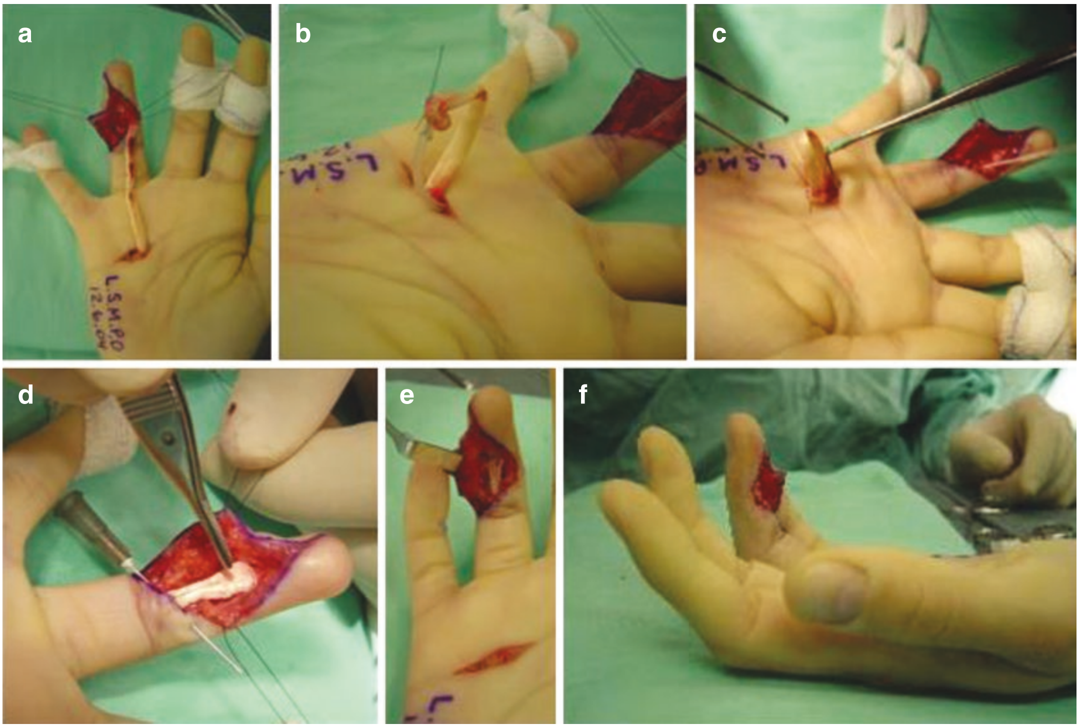

Fig. 5.10 Surgical technique; (**a**) palmar incision to find retracted tendon; (**b**) tendon secured by nasogastric tube; (**c**) tendon passing pulley system; (**d**) tendon stump security in proper location to repair; (**e**) tendon repaired; (**f**) normal cascade achieved

the loss of strength from the deficient FDP can be troublesome, especially in athletes. Stiffness of the PIP joint can occur, often with some degree of fixed flexion contracture [20]. Fortunately, these injuries are rare [21]. After the surgical TREATMENT, the finger should be splinted dorsally to limit DIP extension [22] (Fig. 5.11).

5.6.2 Type II

Type II injuries occur as the avulsed tendon retracts to the level of the FDS decussation at the PIP joint, because there is a small bone fragment. These are the most common form of avulsions [21]. As only the short vinculum is ruptured, some of the blood supply is maintained; therefore, these injuries can be treated within 3 months with good results [21].

Fig. 5.11 Postoperative splint

Silva et al. have shown that the FDP tendon hypertrophies after it is divided from its insertion site, and at 21 days the tendon still is able to hold a suture well [23] which reinforces the notion that delayed repair is still possible.

Fig. 5.12 Example of type II lesion being repaired with mini-anchor

However, attention must be taken because in a minority of cases tendon's retraction may occur; if it happens, the injury is converted to a type I injury, with the commensurate prognosis. Type II injuries generally have a better prognosis than type I.

The aim of the treatment is similar to type I (Fig. 5.12), reattach the FDP stump to be secured directly to the footprint in the distal phalanx when the knot is secured [13, 24.]

5.6.3 Type III

Type III injuries involve a larger piece of the bone that gets caught at the level of the A4 pulley. The blood supply in these cases is not an issue, because both vincula remain intact.

It can be misdiagnosed because the DIP joint can show a minor flexion through the vincula action; on the other hand, radiographies aid the diagnosis [13].

The bony injuries can be treated by open reduction and internal fixation of the fracture fragment, which indirectly repairs the tendon. The osteosynthesis can be done with miniplates and cortical screws (Fig. 5.13) or with lag screws for avulsed fragments of sufficient size [25, 26]. If the fracture fragment is too small for fixation, the tendon should be reattached directly to the distal phalanx.

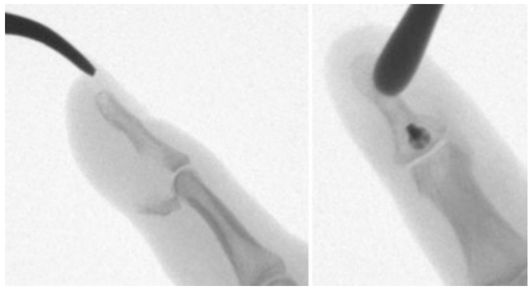

Fig. 5.13 Example of type III lesion being treated with mini-screw

5.7 Rehabilitation

A dorsal blocking splint must be worn for 4–6 weeks after tendon surgical repair (by surgeon's confidence). Strengthening exercises begin 8 weeks postoperatively if full range of motion is present [27].

The objective of rehabilitation is to restore the patient to optimal function. In athletes whose function exceeds that of the general population, the goal is to restore function sufficient to withstand the demands of their chosen sport [28]. In general, the goals of rehabilitation of the athlete should be the following:

1. Control inflammation and pain
2. Restoration of pain-free range of motion
3. Resistance training to restore strength
4. Higher-intensity, sports-specific exercises
5. Gradual and/or protected return to play

5.8 Return to Sport

A premature return to sport may result in complications and potentially permanent sequelae that could be preventable. Decisions regarding return to play after injuries are an important and challenging aspect of caring for athletes. One reason that makes the decision harder is the competing interests and parties including the athlete, coaches, trainers, agents, and organizations.

To allow return to athletic activities, many factors should be considered: nature of the lesion, the strength of fixation, duration of time away from sports, short- and long-term career, and ethical, legal, and financial issues in professional athletes.

Patients generally may not return to sport for a minimum of 3 months following surgical repair of the tendon [24].

5.9 Complications

When a FDP lesion is not diagnosed and treated accordingly, in addition to the incapacity to flex the DIP joint, scarring and pain at the site of the distal tendon stump, instability of the DIP joint, weak PIP joint flexion, and finger stiffness can also occur [15]; dorsal subluxation of the distal phalanx with chronic untreated injuries was also reported [21].

Chronic tendon rupture can be repaired with tendon grafting with satisfactory results although it fails to regain their preinjury range of motion [29]. When there is instability of DIP after a mistreated jersey finger, arthrodesis (Fig. 5.14) might be helpful to permit the return to sport [30].

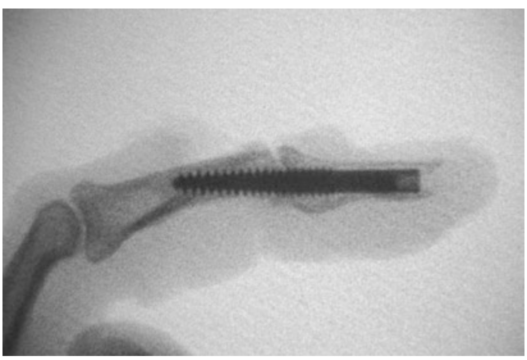

Fig. 5.14 Arthrodesis of DIP joint

Despite the adequate treatment, studies have demonstrated a loss of DIP joint extension of 10–15°, and both DIP joint flexion and grip strength were largely intact [31, 32].

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6 A Guide to Diagnosis and Treatment: First CMC Joint Articular Fractures

Didier Fontès

6.1 Introduction: Basal Joint Trauma in Combat Sports

The basal joint of the thumb is frequently involved in combat sports injuries. The mechanism of the traumatism depends on the type of sport itself.

For example, hand trauma during practice of judo is function of the "Kumi-Kata" which is the type of grasp of the opponent judogi (or kimono). For a dominant right-handed judoka, classical Kumi-Kata consists in gripping the left elbow of the adversary to give the orientation of the movement; during this phase, the thumb can be overtwisted and injured (Fig. 6.1). The right hand classically holds the collar or the belt and contributes to the strength; axial loads can be applied to the first column (Fig. 6.2). Some positions are forbidden and could be dangerous for the thumb (Fig. 6.3). Prevention of trauma consists in the strict respect of the rules and strapping of the first column (Fig. 6.4), but judo remains a combat sport with harsh and frequent contacts with the opponent and sometimes unfortunately also with the tatami too. Other martial arts (karate, jujutsu, etc.), implying frequent contacts with the hand, can also involve first carpometacarpal joint (CMC J) injuries [1].

English boxing provides also classically trauma of the thumb [2] and especially fractures of basal first metacarpal (M1) bone even if the fists and fingers are protected by a strapping and padded gloves whose weight depends upon the category. If the technique is accurate, the impact is located on the second and third flexed metacarpophalangeal joint. Strength measured with a dynamometer can be estimated up to 4800 ± 227 Newton for the back hand (more frequently the right one) and 2847 ± 225 Newton for the forward hand. Fractures represent approximately 84% of declared injuries during professional matches, and the hand is involved in 50% and the thumb in half of these fractures. A non-adapted glove with the thumb too far from the other fingers can be the explanation or an impact on the radial aspect of the hand during an uppercut or a "hook" (Fig. 6.5).

We observe also frequent Bennett's fractures or first CMC joint trauma in collective combat sports like rugby or American football [3].

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Fig. 6.1 Classical Kumi-Kata, elbow gripping of the judogi

Fig. 6.2 Classical Kumi-Kata, collar or belt gripping of the judogi

6.2 Diagnosis and Description of First CMC Joint Articular Fractures

6.2.1 Clinical and Radiological Assessment

Combat sportsmen are classically tough and can bear a lot of physical pain. So, after thumb trauma, they generally don't care immediately and can finish their match, but secondary painful swelling draws the attention to the problem and will limit thumb activities. Physical examination is painful and can find basal joint cracks or deductible dislocation. Plain X-ray is systematic, and orthogonal incidences (as described by Adalbert Kapandji) centered on trapezio-metacarpal joint [4] must be prescribed (Fig. 6.6). It can be sufficient for the diagnosis of extra-articular fractures, but in case of associated dislocation or visualization of an articular separation, *3D CT scan* is required.

6.2.2 Description of the Fracture

Basal joint injuries can involve independently or associate a fracture of the first metacarpal bone (M1), a fracture of the trapezium, and lesion of first CMC J ligaments (± dislocation). The assessment of those different lesions will give us the description of the fracture and orientates the

Fig. 6.3 Forbidden Kumi-Kata potentially dangerous for the thumb column

Fig. 6.4 Preventing strapping of the first column

Fig. 6.5 Impact on the radial aspect of the hand during boxing

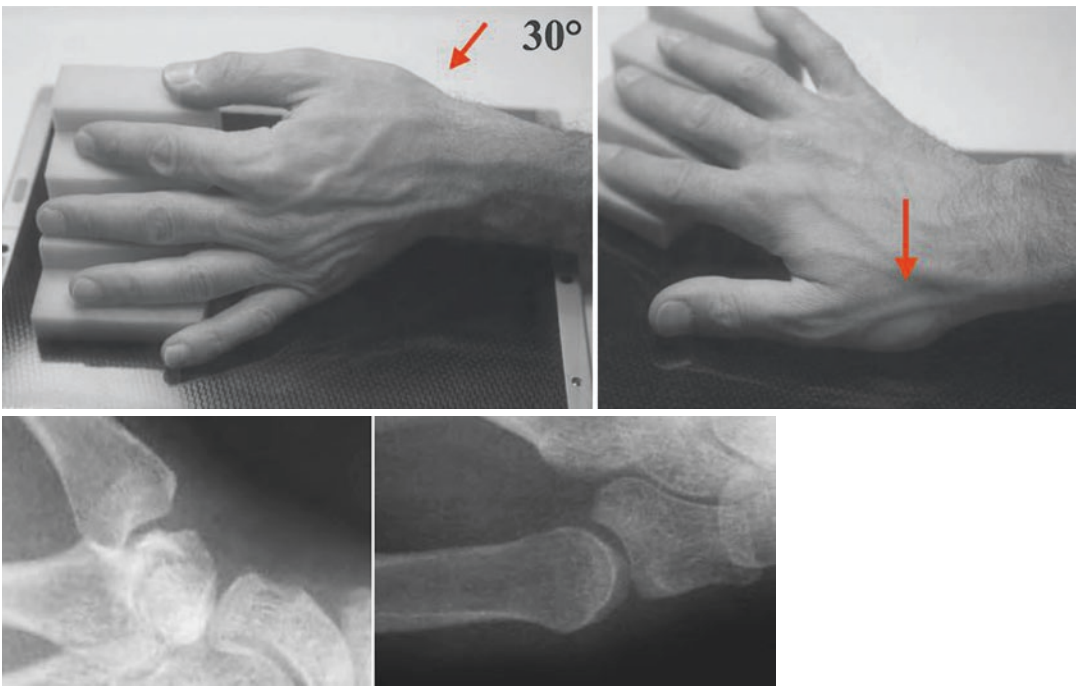

Fig. 6.6 Kapandji incidences for basal joint centered plain X-rays

therapeutic management [5]. M1 fractures can be classified depending on the type of fracture itself (Fig. 6.7).

1. *Bennett's fracture* was described by Dr. Edward Bennett, who suffered a fracture-dislocation of his thumb while horse riding in 1882. It is also known as a "boxer's fracture," because the mechanism of injury is often a traumatic force going down the length of the first metacarpal bone, where there is a semi-bent CMC joint (i.e., a punching movement).

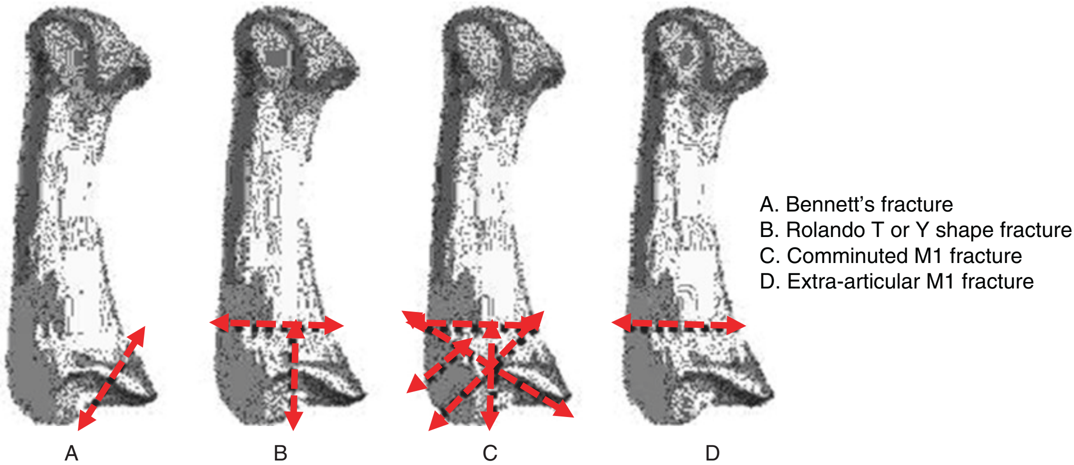

Fig. 6.7 Classification of basal thumb metacarpal fractures

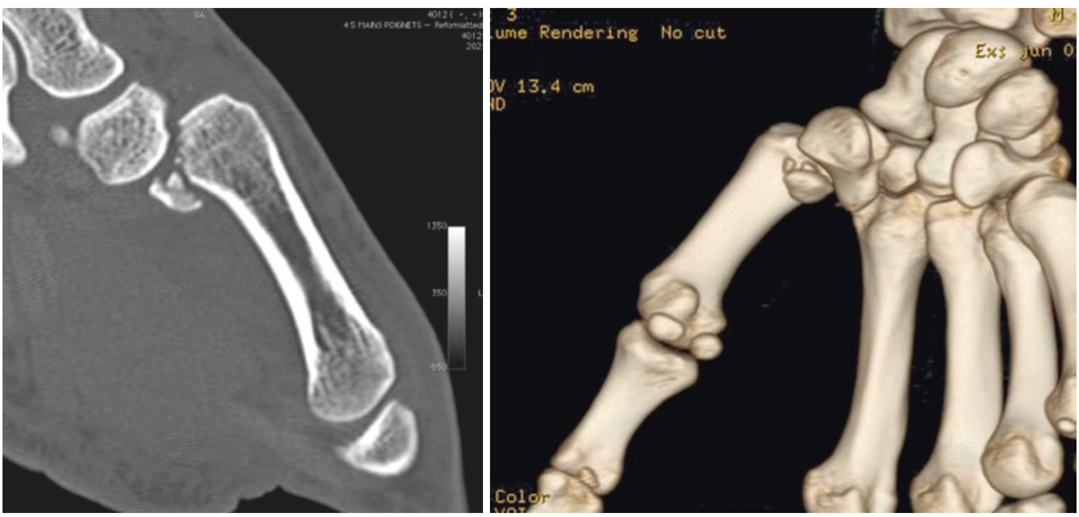

Fig. 6.8 Bennett's fracture-dislocation of M1

It is a fracture-dislocation of the thumb not uncommon in boxers, rugby players, American football players, and football (soccer) goalkeepers. It refers to an oblique fracture of the ulnar aspect of the first metacarpal bone at the joint surface with the trapezium where important ligamentous stabilizers are normally inserted causing a dislocation of the joint increased by the tension of the abductor pollicis longus tendon attached on the basis of M1 [6]. Hence this injury is referred to as a thumb "fracture-dislocation" (Fig. 6.8).

2. *Rolando fracture*: It was first described in 1910 by Silvio Rolando [7–9]. This is an articular fracture consisting of three more distinct fragments; it is typically T- or Y-shaped (Fig. 6.9). This type is more uncommon and has a worse prognosis than Bennett's fractures.
3. *Comminuted M1 fracture* consists in a multifragmental basal joint fracture which can also be associated with large ligamentous lesions (i.e., dislocation). This type of fracture is more uncommon than the precedent described and

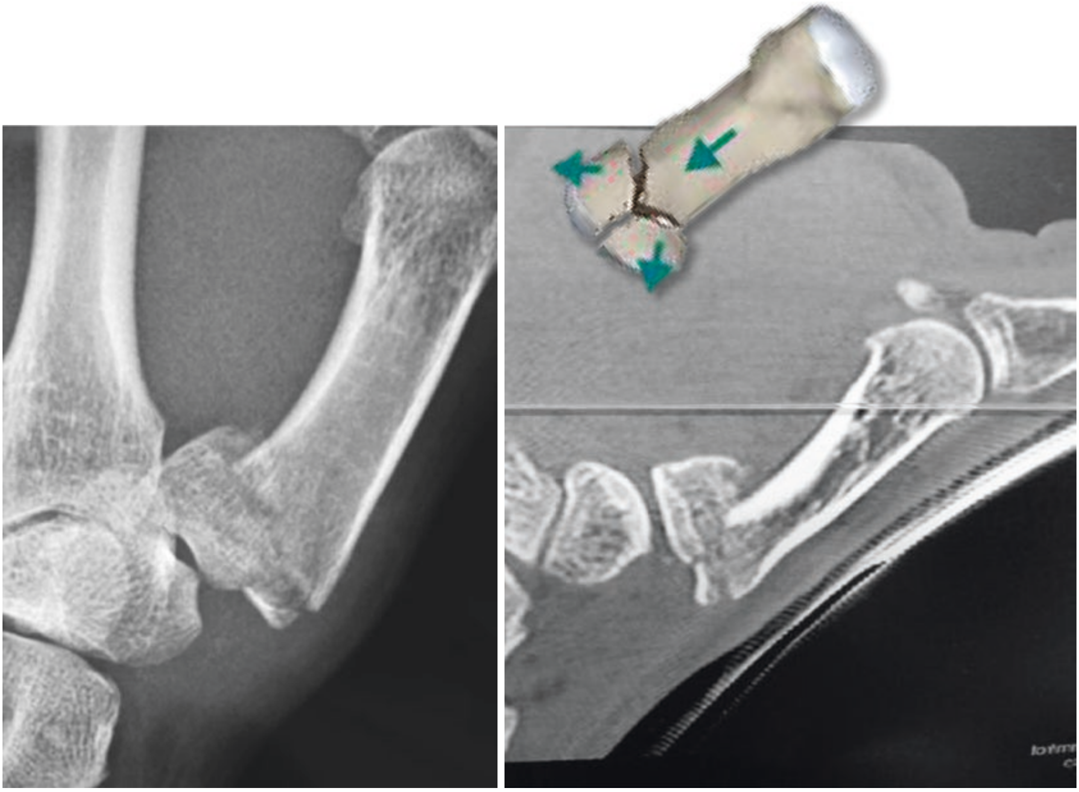

Fig. 6.9 Rolando fracture of M1

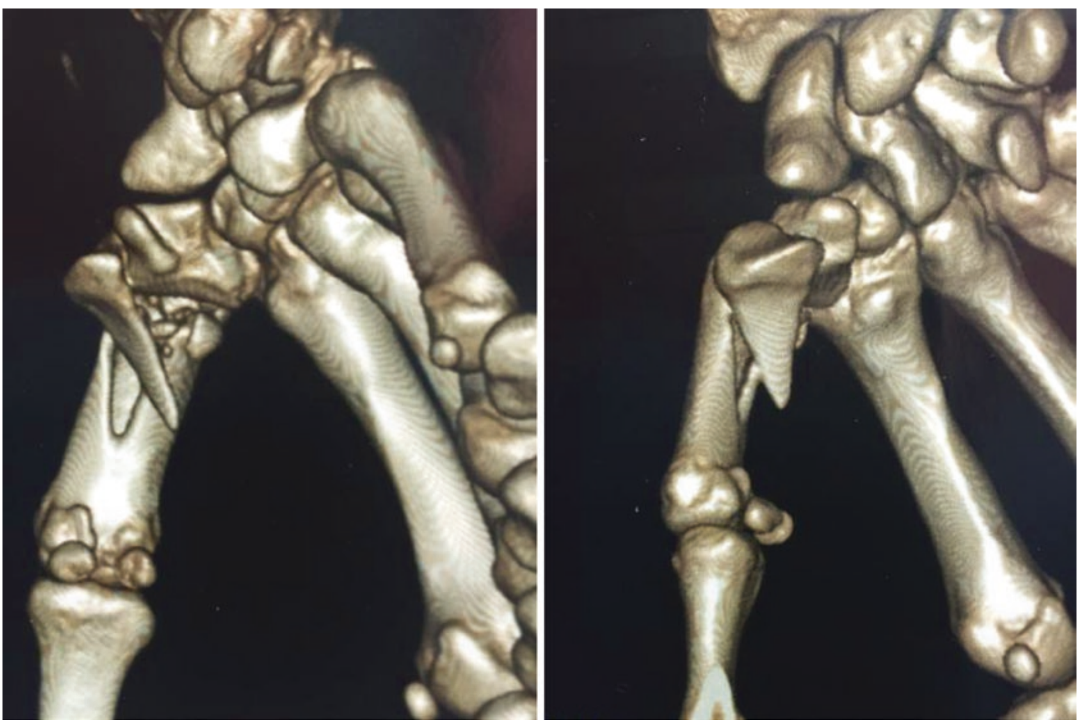

Fig. 6.10 Comminuted fracture-dislocation of M1 in a professional rugby player

more characteristic of high energy trauma as experienced in rugby or American football rather than judo or boxing (Fig. 6.10).

4. *Extra-articular M1 fracture*: There is no articular line, but excessive bending or displacement will lead to a surgical management (Fig. 6.11).

5. *Fracture of the trapezium* can be associated to a M1 fracture and a dislocation or isolated. They are more unlikely (3–5% of carpal fractures) and can be discovered during CT scan exploration (Fig. 6.12). Specific management of this fracture will be required [10–15].

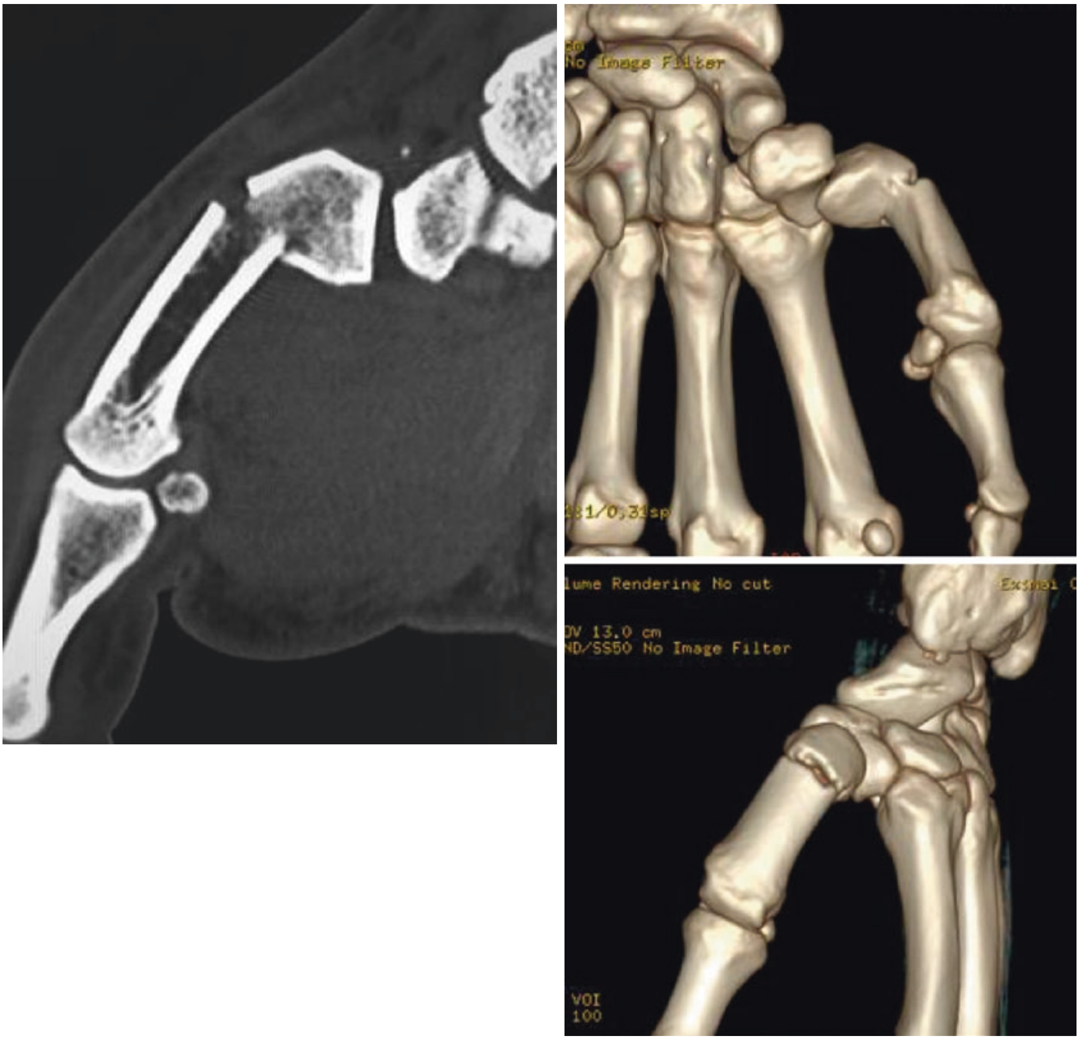

Fig. 6.11 Extra-articular displaced fracture of M1

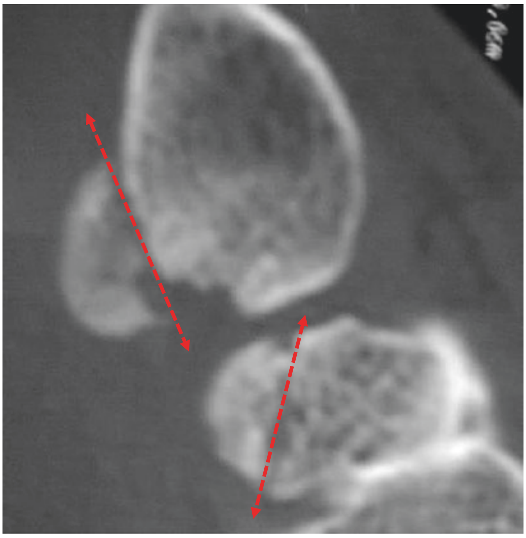

Fig. 6.12 Bennett's fracture + fracture of trapezium

6.3 Treatment

Because of the combination of damage to the joint surface of the metacarpal and the joint instability caused by the osseous detachment of the deep ulnar ligament, the incidence of long-term degenerative joint arthritis in the CMC joint is high following a Bennett's fracture [16, 17]. Also, displaced Bennett's fractures that are managed conservatively tend to experience a fair degree of functional impairment, such as re-dislocation and subluxation during work and sporting activities. Consequently, we advocate surgical fixation to repair an articular fracture-dislocation. Even following surgery there is a reasonably high level of long-term arthritis of the first CMC joint. As with any joint reconstruction, the outcome is very much dependent upon the surgeon's skill in realigning the normal joint anatomy [18–20]. More than 20 methods of treatment have been described. Techniques have gone from orthopedic conservative treatment to open reduction internal fixation or by percutaneous methods of closed pinning. This lack of consensus shows that there is no single ideal fixation method even 134 years after the original description by Edward H. Bennett. Even if the relationship between articular malunion and bad functional results is still debated, yet numerous clinical and cadaveric studies have shown that achieving anatomical reduction remains the single target of priority whatever articulation is involved.

In 2012, Culp and Johnson [21] described a percutaneous screw osteosynthesis under arthroscopic control, claiming that fluoroscopy did not allow satisfactory control joint reduction. During the SOFCOT meeting in 2015, we have presented our 4 years' experience of management of Bennett's fracture under arthroscopic control [22], and Liverneaux [23] and Dautel [24] have published their results in arthroscopic management. Regarding the relative complexity of this articulation (double saddle shape), we consider that only arthroscopic control makes it possible to evaluate accurately the reduction and the stability of basal joint articular fracture. Preoperative fluoroscopy is insufficient [25] and notable to assess frequent associated ligamentous lesions whose physiology remains controversial and anatomy complex (up to 17 ligaments have been described) [26, 27].

Classical arthroscopy advocated [28, 29] by Culp, Dautel, and Liverneaux consists in an axial vertical traction of the thumb and approaches throw 1R and 1U portals (Fig. 6.13).

In our experience, it appears to be relatively tedious to manage either fluoroscopy, arthroscopy, or osteosynthesis in this position, and we have proposed another procedure for this technique.

Our preferred method is based on Gedda's classification (Fig. 6.14) depending on the size and displacement of the volar and ulnar fragment [30].

- The first step consists in an inter-metacarpal pinning under fluoroscopic control such as the Iselin technique [31, 32] with a relative traction on CMC J 1 (Fig. 6.15).
- The second step is the arthroscopic assessment of the basal joint trough 1R, 1U, or volar classical portals but with the hand lying on the table. It gives us more handiness rather than working in a vertical position and especially for the fluoroscopic control (Fig. 6.15).
- Reduction of the ulnar fragment is performed under mixed endoscopy and fluoroscopy, and its synthesis (Fig. 6.16) is carried out depending on its size regarding Gedda's classification (K wire or cannulated compressive screw).

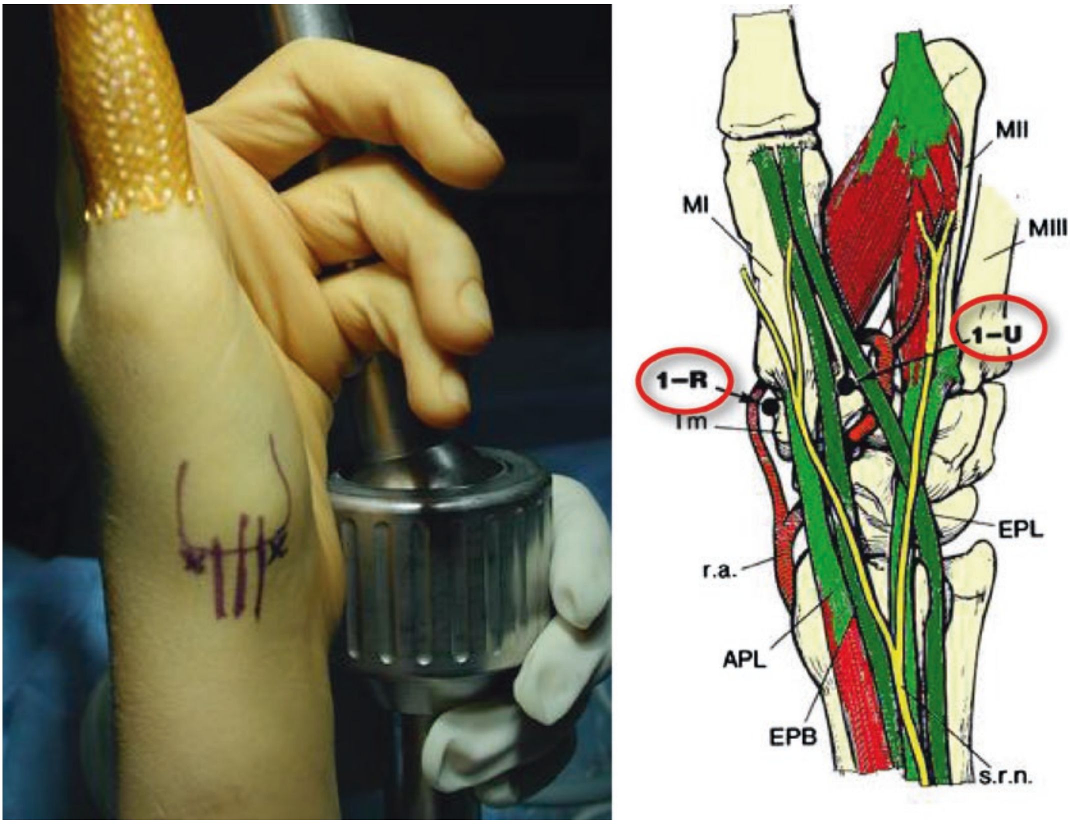

Fig. 6.13 Classical installation and portals for basal joint arthroscopy

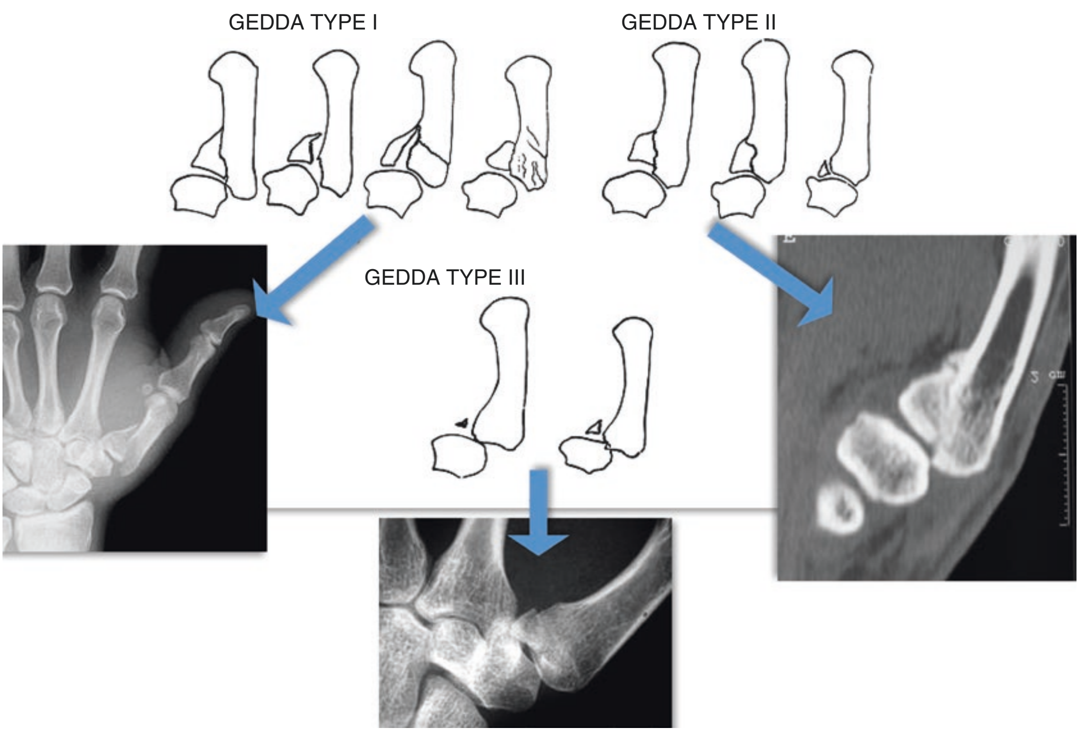

Fig. 6.14 Bennett's fracture Gedda's classification

Fig. 6.15 Bennett's fracture arthroscopic reduction, assessment of associated ligamentous lesions after temporary inter-metacarpal pinning

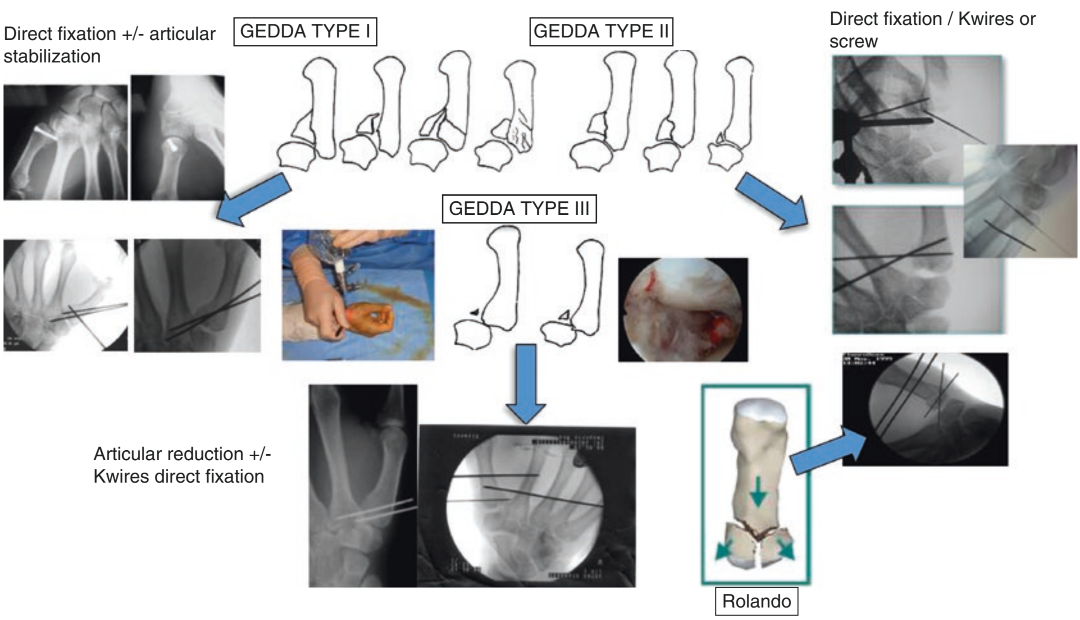

Fig. 6.16 Our indications depending on Gedda's classification

– Assessment of ligaments is completed and can advocate for a surgical reattachment or a simple debridement (Fig. 6.17).
– The last step consists in the testing of the stability of the synthesis, and in the absence of ligamentous-associated lesions, inter-metacarpal K wires are removed, and immediate motion can be authorized. In other cases, a splint is performed and kept during 3–6 weeks depending on associated lesions.

Following surgery, rehabilitation can be resumed once the surgeon has given the go ahead and removed any splint. The goals of

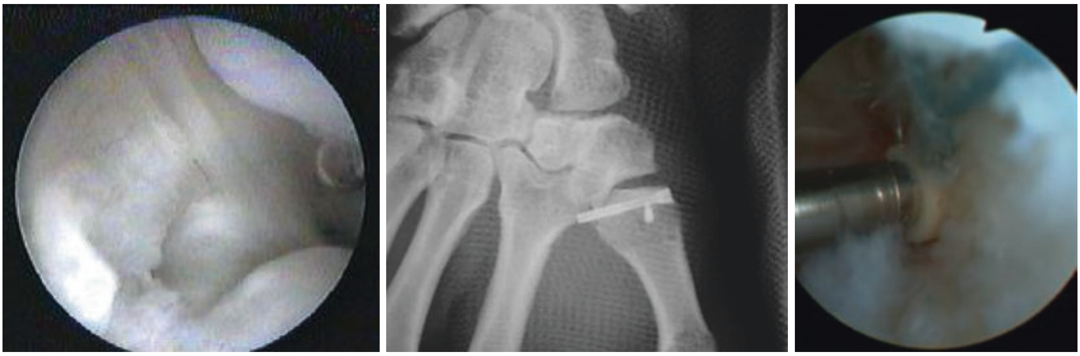

Fig. 6.17 Arthroscopic ligamentous lesions assessment and treatment

rehabilitation are to relieve stiffness, restore range of motion, and increase progressively muscle strength. Hand function is gradually restored to normal over a 3 months' period, although the thumb may sometimes not feel right for around 6 months [27].

Exercises using hand therapy balls can be very helpful to regain mobility. Grip and thumb strengthening devices can also be useful to restore normal hand and thumb strength before return to sport and competition which is generally possible after 2–3 months with the protection of a strapping.

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7 Hand and Wrist Injuries in Mixed Martial Arts

M. Lucius Pomerantz

7.1 Introduction

The sport that we call mixed martial arts (MMA) is different from other more "traditional" martial arts in that it employs striking and grappling techniques from multiple disciplines. It is related to other "no-holds-barred" fighting disciplines such as pankration, which dates to Greek antiquity [1]. While MMA is not unique in combining many forms of combat, it is unique in its recent development and evolution to sport. It was not until 1993 when what we consider modern day MMA began to take form. In that year the Ultimate Fighting Championship (UFC) was started with the intention of placing competitors of different martial arts against each other to see which art was the most effective in combat. It was a "no-holds-barred" event meaning that minimal rules governed what techniques could be used against one another. It was overtly violent and, comprised of many size and skill mismatches. Many found it distasteful. The public backlash resulted in the sport being banned in many states within the United States of America (USA). However, in the late 1990s and early 2000s, an effort was made to increase the safety of the sport and make it more spectator-friendly. Since that time, the sport has evolved greatly and experienced a surge in popularity making it one of the fastest growing sports in the world [2]. It was reported in 2012 [3] that 5.5 million teenagers and another 3.2 million children participate in MMA in the USA, which is comparable to other more traditional sports such as baseball and American football. The UFC recently sold for over $4 billion reflecting its worldwide presence and popularity [4]. As the sport has evolved, what used to be a contest of one martial art versus another has become a combination of those arts and a new sport in itself.

Given the popularity of the sport, it is important for physicians and surgeons to be able to understand and anticipate the injuries that athletes may sustain during their participation. Given the overlap of MMA with boxing, wrestling, Brazilian Jiu Jitsu, judo, Muay Thai kickboxing, and other martial arts (see Table 7.1), there is also an overlap in the occurrence of injuries. However, MMA is its own sport that does require its own analysis. This article will emphasize the rules, techniques, and equipment that may contribute to injuries of the hand and wrist as well as a review of the current available literature. As a former competitor in MMA and a fellowship-trained hand surgeon, I have a unique perspective and access to the sport.

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Table 7.1 General comparison between various martial arts

Martial art	Strikes with the hand (fists)	Strikes with elbows or forearm	Strikes with knees	Strikes with kicks (including shin or foot)	Biting	Strikes with the head	Throws or takedowns	Fighting on the ground	Submissions	Chokes	(Generalized) targeted areas	Fight area	Gloves/ weight of gloves	Apparel (based on highest competition level)	% with hand/wrist injury (if available)
Judo[a]	No	No	No	No	No	No	Yes[b]	Yes	Yes	Yes	Extremities or neck	Mats with defined out of bounds without barrier	No	Gi with belt	6–30 [5–7]
Wrestling[c]	No	No	No	No	No	No	Yes[b]	Yes	No	No	Extremities or neck	Mats with defined out of bounds without barrier	No	Singlet and specific foot wear	3.5–11.0 [6, 8–10]
Brazilian Jiu Jitsu[d]	No	No	No	No	No	No	Yes	Yes[b]	Yes	Yes	Extremities or neck	Mats with defined out of bounds without barrier	No	Gi with belt or low profile clothing for no Gi contests	11.1 [11]
Sambo[e,f]	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Extremities or neck	Mats with defined out of bounds without barrier	Dependent on venue/ 4–6 oz	Gi top, shorts, headgear, mouth guard, groin protection, open fingered gloves, leg pads covering the front part of the shin and lacing of specific foot wear	NA
Karate[g]	Yes	No	No	Yes	No	No	Yes	No	No	No	Head and trunk	Mats with defined out of bounds without barrier	Dependent on venue/4–10 oz	Kimono with belt, body protection, karate mitts, foot pads, shin pads, mouth guard, with or without groin protection	3.0–12.5 [12–14]

Boxing[h]	Yes[b]	No	No	No	No	No	No	No	No	No	Head and trunk	Enclosed area within ropes	Yes/8–10 oz. for competition up to 16 oz. for training	Shorts, specific foot wear, groin protection, mouth guard, hand wraps with or without headgear	6.5–17 [6, 15–17]
Muay Thai[i]	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	Few restrictions	Enclosed area within ropes	Yes/8–10 oz. for competition up to 16 oz. for training	Boxing gloves, hand wraps, shorts, groin protection	2.3–2.9 [18, 19]
Taekwondo[j]	Yes	No	No	Yes[b]	No	No	No	No	No	No	Head and trunk	Octagonal mats with defined out of bounds without barrier but on platform	Dependent on venue (becoming more common) /4 oz	Dobok with trunk protector, headgear, mouthpiece, groin area protector, gloves, and shin and forearm guards	8–10.8 [7, 20, 21]
MMA[k]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Few restrictions	Enclosed area within ropes or cage	Yes/4–6 oz	Gloves, hand wraps, mouthpiece, shorts, groin protection	5–17.7 [22–28]

[a]http://www.nbcolympics.com/news/judo-101-rules-scoring#scoring
[b]Primary attack (perhaps numerical classification in a seperate location)
[c]http://www.nbcolympics.com/news/wrestling-101-rules
[d]https://www.usgrappling.com/rules/
[e]Some variations of rules allow striking (perhaps numerical classification in a seperate location)
[f]http://sambofias.org/uploads/documents/FIAS/FIAS_Sambo_Rules_2015_EN.pdf
[g]http://www.wkf.net/pdf/wkf-competition-rules-version9-2015-en.pdf
[h]http://www.teamusa.org/usa-boxing/rulebook/competition-rules
[i]http://www.ikfkickboxing.com/RulesMT.htm
[j]http://www.worldtaekwondofederation.net/rules/
[k]http://www.ufc.com/discover/sport/rules-and-regulations

7.2 Mixed Martial Arts

To understand MMA, one should have a brief understanding of the terminology involved. Martial arts are the practice of combat and self-defense and have likely existed for as long as civilization [1, 29]. There are many different types of martial arts with different cultural influences and emphases, but all have the objective of engaging an opponent in direct combat. Often, they become sporting contests with rules that dictate the objectives of the contest and increase safety. For MMA, what used to be a contest to see which martial art is superior has morphed into a combination of the martial arts, hence the name mixed martial arts.

There are countless techniques that one can use against another person to gain superiority in combat, but they can be organized into general categories. "Striking" is when a person uses their extremities to strike their opponent and requires some distance, also known as range, between the combatants. Strikes in MMA most often involve the hands in the form of a closed fist but, for example, can also be with an open hand (fingers extended), elbows, knees, shins, or the feet. "Grappling" involves closer range combat that requires grasping of the opponent. Grappling often involves bringing the engagement to the ground via a throw or "takedown." Other attacks include joint manipulation such as hyperextension or twisting and have been termed "submissions." To successfully use a "submission," torque on the joint is created by applying force through moment arms proximally and distally to the joint. An example of this would be by performing an "arm bar," which creates hyperextension at the elbow by directing force on the humerus in one direction and then applying an opposite force through the forearm (Fig. 7.1). Chokes are attacks where the ability to breath and/or blood supply to the brain is temporarily cut off. The opponent can concede, or "submit", to their opponent before injury, or unconsciousness occurs via signal. Often the signal will be tapping their hand repeatedly onto their opponent or "tapping out," but the signal can also be verbal.

7.3 Rules in MMA

Unified Rules and Regulations of Mixed Martial Arts exist [30] and contributed to the growing acceptance of the sport. I intend to summarize the rules in a way that applies to the goals of this paper. For a full list of rules and regulations, see reference. A general comparison of martial arts can be seen in Table 7.1 including legal techniques, fighting area, and apparel.

The Fighting Area: The contest usually takes place on a flat surface with foam padding and lined with canvas or similar material to prevent

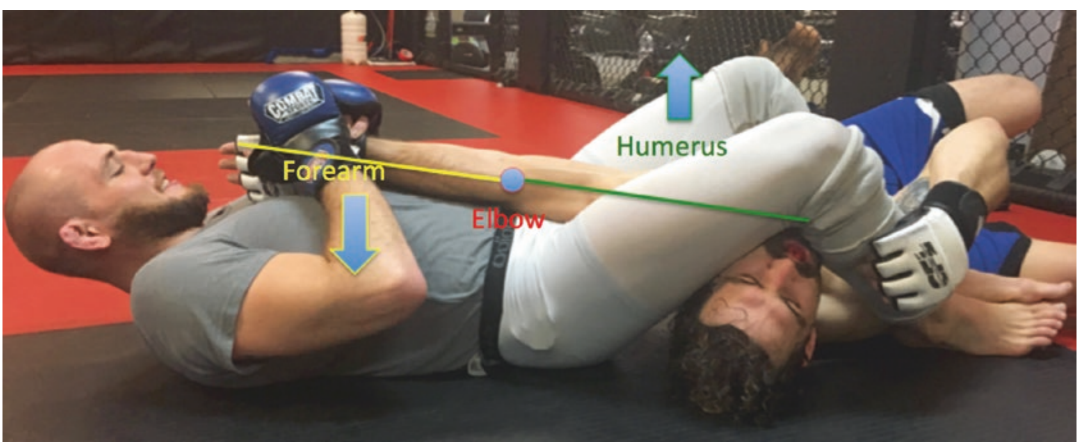

Fig. 7.1 Arm bar

Fig. 7.2 Mixed martial arts gloves/boxing gloves. Standard MMA glove with open fingers compared to 16 oz. training/sparring boxing glove

slipping if wet. It may be bordered by a chain link fence or "cage" of various shapes or may be similar to a boxing ring lined with ropes. The most famous example is in the UFC, which trademarked an eight-sided cage or "the Octagon." It is illegal to intentionally grasp the cage or fence although leaning into or pushing off of it or pushing one's opponent against it are common tactics.

Potential Injuries: The fighting area itself is a rare source of reported injuries as grasping the cage or fence is illegal; however, it is a possibility that a digit may become caught within the cage or the junction with the floor, resulting in a twisting or avulsion type of injury. In a small survey [22], 12% of respondents did report an injury as a result of the cage.

Fighting Apparel: Include groin protection, shorts or similar lower extremity clothing, mouth guard, hand wraps, and gloves. The gloves are usually 4 oz. (113 g) but can be 6 oz. (170 g) for larger-sized fighters. The gloves have open, independent fingers with padding extending over the metacarpophalangeal (MCP) joints and the proximal phalanges but end at the proximal interphalangeal (PIP) joints (Fig. 7.2). In comparison, modern competition boxing gloves weigh 8–10 oz. (227–284 g) and completely enclose the fingers and thumb, which cannot be separated from the fist (Fig. 7.2). Lastly, but importantly, it is illegal to grasp the apparel.

Potential injuries: Gloves for combat sports are utilized primarily to protect ones hands [29, 31, 32] and not necessarily the opponent being struck. Closed-fisted punching is more utilized in striking arts when gloves are allowed as they reduce the risk of injury to the person throwing the punch [29]. In MMA, since the fingers of the gloves are independent, they are subject to forces not seen in boxing such as twisting, hyperextension, and similar type of injuries. With the gloves ending at the proximal phalanx, the PIP joint likely sees increased forces. An example of an injury is seen in the publicly available photo of UFC fighter Josh Emmett with an open ring finger dorsal PIP joint dislocation (Fig. 7.3). Also, the thumb, in its lateral position on the hand, can be snagged or impacted while throwing punches that is not possible with modern boxing gloves (see representation in Fig. 7.4). Older boxing gloves had an independent thumb, and Noble [31] noted in a study in 1987 that 39% of boxer's injuries were to the thumb and the majority

Fig. 7.3 Josh Emmett open ring finger PIP dislocation injury

Fig. 7.4 Example of independent thumb being deviated away from the hand during a punch

(23/39 injuries) of these were ruptures of the MCP joint ulnar collateral ligament (UCL). Additionally, the smaller gloves in MMA compared to boxing impart similar force to a smaller area resulting in higher peak forces [33, 34] with potentially increased injury to the hand compared to larger gloves.

Since grasping clothing is not legal, the risk of some injuries is reduced. When fingers can be caught in clothing, shear and twisting injuries to the fingers such as flexor digitorum profundus (FDP) avulsion injuries also known as "jersey fingers," pulley injuries, and other sprains can occur. Sports where gripping clothing is very common, such as judo [5] and Brazilian jiujitsu [11] are noted to have these types of injuries. In the survey [22] of MMA fighters, only 2% of injuries were directly blamed on the apparel worn such as getting the fingers snagged within the shorts of their opponent.

Rules of Engagement: Specific rules in place for overall fighter safety also contribute possible hand injuries in MMA. Some injuries are less likely due to the illegality of grasping the cage or the opponent's clothing as previously discussed but also because finger joint manipulation is illegal. Other rules that contribute to a unique injury profile for MMA include the legality of kicks, but illegality of striking the back of the head or neck as well as kicking or kneeing the head of a downed opponent. These will be discussed in further detail in the coming paragraphs.

A rule that fortunately prevents many injuries to the hand and fingers is that intentional finger joint manipulation is not allowed. This means that a person may not grab an individual finger and bend or twist it. Manipulation of the wrist joint is legal but is less commonly targeted compared to other larger joints. It is difficult to isolate the wrist joint and keeping it trapped compared to larger joints, which have longer moment arms that are easier to grasp and manipulate.

Potential Injuries: As mentioned before, striking with a closed fist is the most commonly employed strike in MMA, and an injury profile similar to other striking sports like boxing is expected. However, there are several ways in which MMA may allow for different hand injuries compared to other striking arts beyond the previously discussed gloves. First, there are often situations when powerful kicks impact the lightly padded defender's hand or wrist potentially causing injury, as may be seen in taekwondo or karate. Also, given the grappling component of MMA, there are many situations where the back of the opponent's head and neck are exposed to strikes; however it is illegal to hit these areas. To avoid executing an illegal strike, one needs to angle or "loop" the punch toward the legal target areas, creating impact on the radial or ulnar hand as opposed to directly over the MCP joints (Fig. 7.5). Specifically, the thumb and second ray as well as the ulnar hand are exposed to forces not usually seen in boxing or

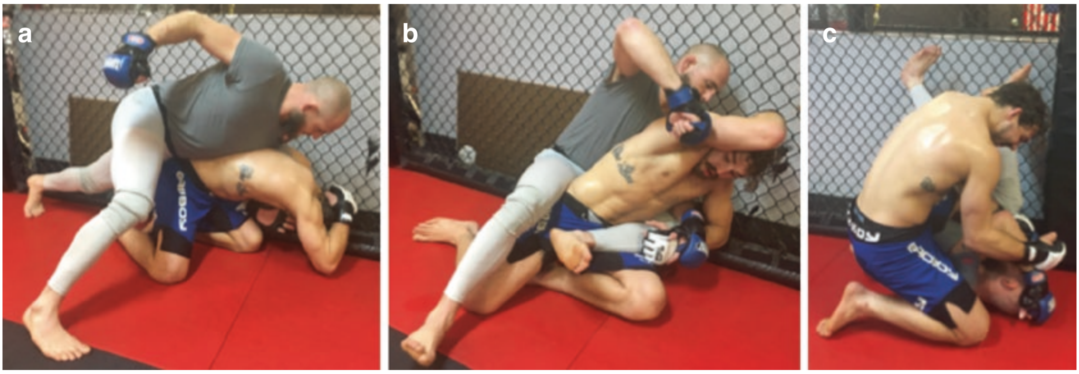

Fig. 7.5 Examples of looping punches to avoid illegal strike (**a**) uppercut from behind (**b**) indirect punch from behind (**c**) hammer punch from top position

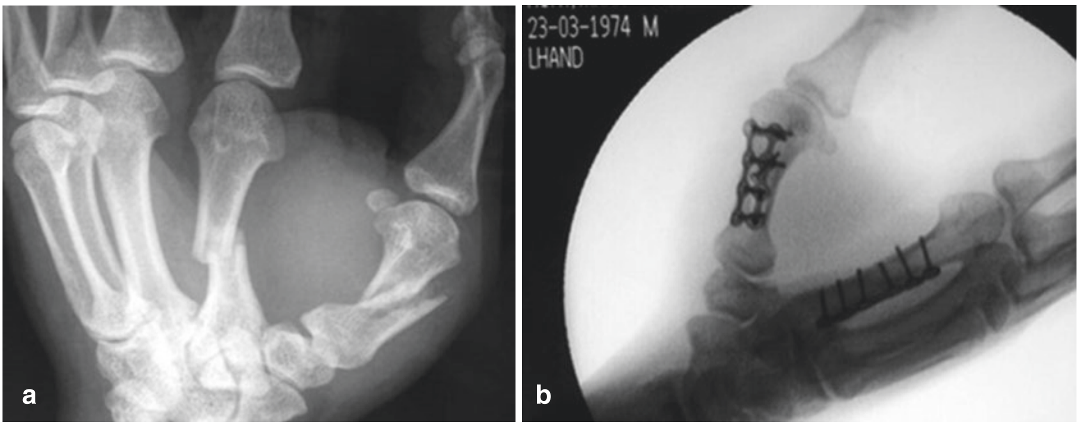

Fig. 7.6 Mark Hunt's fractured hand (source: Mark Hunt's Facebook Page)

kickboxing but are seen in karate or taekwondo. The decreased padding, independent fingers, and unique forces on the hand will result in a unique injury profile. A representative case is UFC fighter Mark Hunt (a former champion kickboxer and now competitor in MMA) who injured his hand and placed photos available publicly on his social media website (Figs. 7.6a and 7.6b).

The ground-fighting component of the sport also contributes to injury. For safety reasons, it is not legal to kick or knee the head of an opponent that has anything but their feet touching the ground. Due to this ground-fighting constraint of MMA, there are situations where the aggressor must use his arms to strike the opponent instead of the legs increasing the chances of injury to the hand. Also, when trying to punch a moving opponent on the ground, it is possible to actually strike the ground instead, which may result in injury.

7.4 Review of Literature

An English language literature search of PubMed, Cochrane, and Google Scholar of "Mixed Martial Arts Injuries" revealed 51 publications. Case reports and articles relating to topics other than injuries to the extremities were excluded. Review of abstracts allowed the search to be narrowed to 11 publications. Review of those articles left eight articles that addressed the goal of assessing the rate of upper extremity

Table 7.2 Review of available articles discussing upper extremity injuries in Mixed Martial Arts

Paper	Year	Type of study	Source of information	Number of matches/ fighters	Average age/ gender	Number of injuries/ fighters injured	Number of upper extremity injuries (percent of total injuries)	Types of injuries (not specific to upper extremity injuries unless specified)	Overall injury rate
Bledsoe et al. [28]	2006	Retrospective cohort study	Nevada State Athletic Commission 2001–2004	171/220	28.5 years/100% male	96/78	21 (21.9%)	Specifics not detailed. Most common injury was facial laceration (47.9% of injuries or a rate of 13.45/100 competitors)	28.6 per 100 fight participations (0.286/exposure)
							Hand: 13 (13.5%)		
							Shoulder: 5 (5.2%)		Hand injuries 13.5% or a rate of 3.8/100 competitors
							Elbow: 3 (3.1%)		
							Arm: 1 (1%)		
Ngai et al. [35]	2008	Retrospective cohort study	Nevada State Athletic Commission 2002–2007	635/1270	NA/100% male	356/300	67 (18.8%)	"Upper limb injuries": occurred in 6.5% decisions, 7.7% of TKO, 3.3% of submissions, and 0% in draws, DQs, Physician ended fights, KOs	23.6/100 fight participations, loser 2.4× more likely to be injured
Rainey [23]	2009	Retrospective cross-sectional study	Survey	NA/55	NA/94.5% male	207	47 (22.7%)	16.2% Strains	NA
							Shoulder: 13 (6.2%)		
							Finger: 9 (4.3%)	14.9% Sprains	
							Elbow: 7 (3.4%)	10.1% Abrasions	
							Upper Arm: 6 (2.9%)	9.2% Joint Trauma	
							Hand: 6 (2.9%)	5.7% Fracture	
							Wrist: 4 (1.9%)	5.3% Lacerations	
								2.6% Dislocations	

Scoggin et al. [26]	2010	Prospective Cohort	Hawaiin MMA competitions from 1999–2006	116/179	Not specified	55/49	8 (14.5%)	1 lateral sprain, 1 medial sprain, 1 subluxation and 1 olecranon bursitis	0.237 injuries per exposure
							Elbow: 4 (7.3%)		
							Metacarpal: 3 (5.5%)	1 fracture, 2 other injuries	
							AC joint: 1 (1.8%)	Separation	
Diesselhorst et al. [32]	2013	Retrospective Cohort	Survey of 758 participants of martial arts regarding upper extremity injuries (38% participating in "multiple martial arts" though included MMA)	NA/758	44 years, 81% male	NA	Hand/Wrist/Fingers: 53% injured	Sprains/Muscle Strains: 47%	NA
							Shoulder/Upper Arm: 27%	Abrasions/Bruises: 26%	
							Forearm/Elbow: 19%	Fracture of upper Extremity: 39%	
								Dislocation: 47%	
Otten et al. [25]	2015	Retrospective Cohort	NSAC (UFC events 2007–2009) Divided into Figher Complaints and Doctor Observations	152/304	NA/100% Male	170 fighter complaints, 91 Physician Observations/120 (based on counting presented data)	*Fighers Complained of:*	*Doctors Noted:*	39.7/100 competitors
							29 (17.1%)	Lacerations/Soft tissue injuries: 58 (63.7%)	
							Hand and Wrist: 15 (8.8%)	Shoulder: 4 (4.4%)	
							Arm/Elbow: 7 (4.1%)	Hand: 3 (3.3%)	
							Shoulder: 7 (4.1%)		

(continued)

Table 7.2 (continued)

Paper	Year	Type of study	Source of information	Number of matches/fighters	Average age/gender	Number of injuries/fighters injured	Number of upper extremity injuries (percent of total injuries)	Types of injuries (not specific to upper extremity injuries unless specified)	Overall injury rate
Karpman et al. [36]	2016	Consecutive case series, observational cohort	MMA bouts in Edmonton 2000–2002 and 2005–2013	1181 fighters	NA/99% male	926/702	Only injury specific to body part was fracture: Hand/arm fractures: 29 (49.2% of fractures recorded)	Contusion: 663 (56.1%)	59.4% overall injury rate
								Concussion: 98 (8.3%)	2.5% of which were hand/arm fractures
								Laceration: 95 (8.0%)	
								Fracture: 59 (5.0%)	
								Eye injury: 3 (0.3%)	
								Dislocation: 2 (0.2%)	
								Other: 6 (0.5%)	
Ji [24]	2016	Retrospective cohort	Survey of 470 MMA athletes Seoul or Gyeongnam province, Korea between 6/2015 and 11/2015	455 fighters (15 surveys excluded)	62.4% between 20 and 29 years/96.3% Male	860/455	Arm: 253 (30.4%)	Laceration: 321 (37.3%)	NA
							Hand: 71 (8.5%)	Concussion: 179 (20.8%)	
							Wrist: 65 (7.8%)	Contusion: 142 (16.5%)	
							Shoulder: 37 (4.5)	Fracture: 53 (6.2%)	
							Forearm: 25 (3%)	Strain: 51 (6.0%)	
							Finger: 15 (1.8%)	Joint: Dysfunction: 45 (5.2%)	
							Elbow: 3 (0.4%)	Sprain: 25 (2.9%)	
								Dislocation: 20 (2.3%)	
								Epistaxis: 15 (1.8%)	
								Other: 9 (1%)	

Pomerantz [22]	2017	Retrospective cohort (not published)	Survey of 93 respondents	93 fighters	79.3% between 20 and 35 years/90.3% Male	215/93	Arm: 59 (27.4%)	Laceration: 5 (5.8%)	NA
							Shoulder: 37 (49.3%)	Concussion: 25 (11.6%)	
							Elbow: 22 (29.3%)	Neck Strain: 24 (11.2%)	
							Hand: 6 (8.0%)	Fracture: 9 (4.2%)	
							Finger: 6 (8.0%)	Strain: 11 (5.1%)	
							Wrist: 2 (2.7%)	Lost Tooth: 7 (3.3%)	
								Sprain: 57 (26.5%)	
								Other: 4 (1.9%)	

injuries in MMA. An additional article was found through references pertinent to the research topic, and another article is pending; submission by the author of this paper and its data is included. Table 7.2 summarizes the findings of these studies.

In the articles reviewed, three articles were based on results from surveys of fighters. In those studies, the percentage reporting injury to the hand and wrist occurred at 9.2% [23], 17.6% [24], and 17.7% [22]. In four observational/record review studies, the rates are 5% [25], 5.5% [26], 12.0% (Nevada State Athletic Commission 2001–2009 as reported by Lystad, et al. [27]), and 13.5% [28]. Another study [32], only looking at upper extremity injuries, noted that 53% of martial artist survey respondents reported upper extremity injuries were to the hand/wrist. Two other studies were not more specific than "arm/hand" [36] or "upper limb" [35], and therefore rates of injury to the hand and wrist could not be assessed in these articles.

Unfortunately, only one article mentions specific injuries to the wrist, hand, or finger in MMA: three metacarpal injuries including one confirmed fracture [26].

Given the heterogeneity of the structure and results of these studies, meta-analysis was not possible.

7.5 Discussion

There is a paucity of published data on injuries in MMA, with even less described for hand and wrist injuries. The studies that exist are limited level 4 studies. The available research shows hand and wrist injury rates of 5–17.7% in MMA. Hand and wrist injuries reported for other martial arts are also limited but include 6.5–17% [6, 15–17] for boxing, 2.1–2.9% [18, 19] for Muay Thai kickboxing, 3.0–12.5% [12–14] in karate, 8–10.8% in taekwondo [7, 20, 21], 3.5–13.4% in wrestling [6, 8–10], 6–30% [5–7] in judo, and 11.1% [11] in Brazilian (Jiu Jitsu). From the limited research, it does not seem that MMA has a higher predilection to hand or wrist injury than other combat sports. This conclusion is also corroborated in a recent review of literature for several martial arts [37].

As previously mentioned, the specific types of injuries sustained in MMA are essentially without description in the literature. There are case examples available to review, and we can make educated guesses on the types of injuries that may occur based on other martial arts. All things considered, from a hand and wrist injury viewpoint, the striking component of MMA is most similar to karate or taekwondo. However, many MMA fighters have trained in boxing or kickboxing and may have habits and training methods conducive to boxing or kickboxing. As opposed to boxing, karate and taekwondo have a combination of striking with hands and feet, with different angles of of strikes being used and with small gloves. For less experienced MMA competitors, especially those with experience in boxing or kickboxing, there may be an even higher risk of injury as they have not adapted to the needs of MMA. Finger joint sprains/dislocations in karate are common including thumb MCP joint injuries [12, 38], and one study [38] attributed it to open-hand strikes or catching fingers within the uniform. The most common fracture observed in karate was a fracture of the neck of the second metacarpal [39], but first metacarpal base fractures were also noted. As cited before, Noble [31] described many thumb MCP joint UCL injuries in boxers when the gloves had an independent thumb. Other injuries he noted were various fractures about the thumb, two scaphoid fractures, injuries to the carpometacarpal joints of the hand including dislocation, metacarpal fractures, and several proximal phalanx fractures [31]. Other boxing injuries described include radiocarpal strains, dislocations or tears of the extensor digitorum communis, and extensor carpi radialis and brevis tears [31, 40].

MMA has additional possible injuries from grappling like those that may be seen in judo, wrestling, or Brazilian Jiu Jitsu. Unfortunately, there is not much described research on the specific injuries in these sports either. Specific injuries described for a single Brazilian jiujitsu tournament [11] include distal interphalangeal joint sprain, thumb sprain, PIP joint dislocation, and ring finger metacarpal fracture. Many injuries to the fingers in judo are attributed to being thrown but also to gripping the uniform [5, 41]. Most of these injuries were sprains and strains or "soft" injuries [5]. FDP avulsion injuries, mallet fingers, and various sprains and strains in the hand have been described in judo [5–7, 41], and a case report of a dorsal distal radioulnar joint dislocation exists [42]. Wrestling hand injuries include many sprains of finger joints including the thumb MCP joint [6, 10], but fractures have been reported [8, 9].

Through this review, in addition to personal experience and observation, it is clear that MMA presents risk of injury to the hand and wrist. This is by the nature of the sport as well as the gloves the competitors wear. While grappling is a large component of MMA, fractures as a result of impact are more likely to occur in MMA as opposed to isolated grappling sports like judo, Brazilian jiujitsu, or wrestling. Unlike boxing or kickboxing, the thumb is exposed during punching, which could result in injuries from direct impact or from being deviated. Also, compared to boxing or kickboxing, where punches are less angled, the strikes in MMA are more similar to arts like karate where strikes come from many different angles and impact the hand differently (Fig. 7.5a–c). The angled punching required in certain situations will focus energy more on the radial or ulnar aspects of the fist resulting in a different injury profile. The gloves themselves contribute to injury as they have independent fingers to help with grasping the opponent but also allow for potential twisting and shearing of the fingers. Additionally, with the gloves ending at the PIP joints resulting in relative deceased range of motion proximally, there are increased forces that the PIP joints experience, which I feel increases the likelihood of PIP dislocations. Multiple PIP dislocations are documented on publicly available photographs on the Internet. The small gloves also result in increased forces to the hand during a punch or while defending strikes, which can result in increased exposure to injury of the hand and wrist. Injuries from the fight area or uniform/apparel other than the gloves appear to be a small contributor to hand and wrist injuries in MMA.

The nature of researching this type of injury profile will continue to be based on surveys which are subject to recall biases by those surveyed, record reviews which are limited in scope and information, and direct observation which has its own limitations in study size, observer biases, and logistical issues such as follow-up. Future research will need to focus on determining the specific injuries and their causes. This will help in the prevention of injuries including possible new designs for the gloves and changes in fight area construction. Additionally, it will help the medical personnel who care for these athletes to better anticipate injuries and treat them.

At this point, we as surgeons of the hand and wrist can expect to see more patients involved in the sport of MMA with injuries similar to other fighting arts but with possibly different injury patterns. Their treatment will also be similar, as the goals will remain the same. These athletes will be as motivated to return to sport as any other athlete and can be expected to take the steps necessary to assure optimal outcome.

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8 Finger Injuries in Judo

Nicole Badur, Riccardo Luchetti, and Rainer Ganschow

8.1 History of Judo

Judo was founded in 1882 by Jigoro Kano (1860–1938), who was an educator, philosopher, and athlete. Jigoro Kano developed judo primarily as a way for moral, mental, and physical education. His Kodokan judo was the cumulation of excessive research and the adoption of different techniques from various schools of traditional jujutsu. In the adopted Chinese logographic characters (kanji), "ju" means "to be gentle" or "to give way" and "jutsu" "art" or "technique." Jujutsu implies a method consisting of a collection of physical techniques. Kano believed that jujutsu was insufficient to describe his art—he changed the second character to "do," meaning "way" or "method," implying a more spiritual and philosophical context. Judo can be interpreted as "the gentle way" in which Kano identified three main aspects: to cultivate ethical fortitude, to expand intellectual capacity, and to apply the logic of combat to everyday living [1]. Judo gained widespread international recognition. In 1964, judo entered the Olympics as a demonstration sport and is an established Olympic sport since 1972, practiced in nearly every country of the world. It is nowadays a popular modern martial art which evolved into a safe unarmed combat sport that can be enjoyed by everyone, but furthermore, it is a principle of life, art, and science.

8.2 Basic Aspects in Judo Training

Judo is practiced in a special building, the dojo, on reinforced mats (tatami) that absorb the impact of falls. Judo players (judokas) wear a special outfit, the judogi, which derived from the traditional Japanese kimono and was the first modern martial arts training uniform. It consists of three parts: a heavy jacket, made from single or double woven cotton that is structured, a lighter canvas pants, and a belt. Double woven jackets, which are usually made for tournaments, are heavier and harder to grab. The structure of the judo pants is even. Two judokas pair up and try to throw the opponent with the back onto the mat. The judoka performing the throw is called tori; the one receiving the throw is called uke. Judo training involves technique training (kata), which is prearranged movements aiming at a controlled and perfect execution of each technique and applying this into a freestyle setting (randori). Partners pair and fight each other but take care not to

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injure each other and to follow judo etiquette [1]. The competition form of judo is the shiai.

8.3 Judo Techniques (Waza)

There are three basic judo techniques. Nage-waza (throwing techniques), katame-waza (grappling techniques) and atemi-waza (striking techniques).

Nage-waza: The judoka will try to throw the opponent from a standing position with speed and control onto his or her back. The standing techniques comprise te-waza (hand techniques), koshi-waza (hip techniques), and ashi-waza (foot and leg techniques). The sacrifice techniques comprise ma-sutemi-waza (supine techniques) and yoko-sutemi-waza (side techniques). *Katame-waza* On the ground, there are three different techniques to outfight the opponent. With osae-komi-waza (holding techniques), the opponent is held for 20 seconds controlled with his back on the ground. Shime-waza (strangulation techniques) can be applied, forcing the opponent to submit prior to losing consciousness. Kansetsu-waza (armlock techniques) are only allowed to be applied to the elbow and also aim at forcing the opponent to capitulate. *Atemi-waza* were meant to inflict pain by hitting and striking and are exclusively practiced in kata. Atemi-waza is not practiced during judo training, randori, or shiai. *Kumi-kata* is grip fighting and not considered a basic judo technique. However, it is an essential element in practicing judo as the first contact with the opponent is fighting for the best grip so that a throw can be conducted efficiently.

8.4 Physiological Requirements of the Judoka

As in other athletically demanding sports, judo requires the judoka to adopt specific physiological abilities and fine motor control involving balance control as well as a specific psychological perception [2]. The physical and mental requirements for judo combine raw force and maximum effort with agility, coordination, and the ability to reflexively act and react. Judo-specific training consists of practicing to fall (ukemi) and to throw. Uchi-komi (repetitive turning into the throw) and nage-komi (repetitive throwing) are essential elements. Specific sequences of movements of different throwing techniques can be practiced by oneself (tandoku-renshu) or with a partner (sotai-renshu). But also strength and conditioning along with flexibility, coordination, and endurance are very important.

8.5 Rules and Regulations in Judo Competition

The rules and regulations in a tournament are continuously refined by the International Judo Federation (IJF) in order to make the sport attractive and to minimize injuries. According to the official rules to date, a judo match is fought over 4 minutes for senior men and women in seven weight categories each. The highest scoring value is an ippon which will win the fight outright. Ippon can be achieved with a perfect throw or the abovementioned ground techniques. Penalizations are given for inactivity, for certain gripping patterns that are thought a high risk for injuries, for dangerous techniques, as well as for disrespectful actions which harm the prestige and honor of judo. In the last two decades, especially judo players from eastern Europe developed new throwing techniques and refined existing traditional Japanese techniques. They specialized on certain ducking techniques, thus levering the opponent into the air by grabbing the judo pants with one hand and the lapel or sleeve with the other. Those techniques do not necessarily endanger the opponent per se but were banned in 2013 in favor of the traditional judo techniques. As consequence, it has been forbidden to grasp the judo pants of the opponent in order to perform a throw or to defend a grip, and thus also interesting traditional judo techniques as kata-guruma (shoulder wheel) (Fig. 8.1) were not performed during competitions anymore. Also in other techniques as ouchi-gari (large inner reap), judo players often used to grab the opponent's

Fig. 8.1 Kata-guruma (shoulder wheel). Tori (blue judo jacket) is ducking under uke, lifting him up, and flipping him like a wheel onto his back. Tori is grabbing uke's pants with a pocket grip

pants to make the throw more effective. Many of the changes of the international judo rules from 2013 that were valid until 2016 concerned grip fighting. Since then, it is also penalized to free the opponent's grip with both hands (Fig. 8.2). Especially hyper-abduction injuries to the thumb could be minimized by forbidding this action during kumi-kata. Freeing the grip with the leg is also not allowed. The new IJF rules from 2017, which are still under a trial phase until the 2017 World Championships in judo, are a bit less strict concerning grip fighting.

Fig. 8.2 The judoka wearing a blue judogi is trying to free the opponent's grip with two hands forcing the opponent's thumb into ulnar abduction. This action is forbidden since 2013

8.6 Injuries in Judo

Since the first time judo was part of the Olympic Games, the skills of judo players have been increasing together with the frequency and seriousness of injuries. Even though professionalism and popularity of judo are growing, scientific literature on judo specific injuries is rare [3]. Many articles focusing on injuries concern complex case reports of rare and severe injuries [4] or are retrospective studies evaluating the risk profile in judo injuries [5]. Only recently a few biomechanical and kinematic studies have been published analyzing technique-related head injuries in judo [6, 7]. Other studies are mostly systematic survey studies. Few prospective studies have been investigating the incidence of injuries at judo competitions of which most have been conducted at single events and are a collection of epidemiological data [8–13]. Only one systematic overview on judo injuries has been published to our knowledge to date [14]. Survey studies during the 2008 and 2012 Summer Olympics showed that judo was among the sports with the highest overall injury rate of about 11–12% which resulted from direct contact with another athlete in over 50% [12, 13]. This is in accordance with the findings of an analysis of national sports injuries in Finland over 14 years [15] and an analysis of the Star of the North Summer Games in the United States in 1994 [16]. However, no detailed data is provided in those studies regarding the severity, location, or type of injury for each sport. Studies indicate different injury frequencies during training and competition. While most studies show a higher injury incidence during competition (49–88%) [10, 12, 13, 17], other researches state that over 70% of all injuries occur during training, supported by the fact that judo players usually spend more time training than fighting [15, 18, 19]. The most common site and mechanism of injury have been shown to vary in the literature. The majority of researchers found that injuries during competition affected the upper extremities most in adult judo players [11, 15] as well as in children [20–22]. Most injuries occurred as a result of defensive maneuvers during a fight in the upright position from being thrown (32.7%) and falling (27.3%) [21], but also groundwork has been mentioned as a mechanism of injury [23]. Only one study highlighted the relationship of a specific throwing technique toward injury frequency. Barsottini et al. [19] found that the ippon-seoi-nage (one-arm shoulder throw) and the tai-otoshi (body drop), followed by the uchi-mata (inner-thigh reaping throw), were the throws leading to the highest injury rates with 23%, 22%, and 9%, respectively. Sex-difference data on judo injuries are inconsistent. In one study, no difference in injury frequency was found between male and female senior judo player [15], while others found that men suffered more injuries than women [24]. In junior judo players, girls sustained more injuries than boys [15, 25]. No differences in the injury distribution by body region or the type of injuries regarding the sex have been reported [26]. The most frequent injury types regardless of the body part were sprains, strains, and contusions [9, 14, 26, 27]. In adult as well as elite competitors, dislocations and sprains prevailed, whereas in children and younger and lower-ranked judokas, upper body fractures were more frequent [22].

8.7 Finger Injuries in Judo

Case reports on complex finger injuries in judo have not been described in the literature to date. A traumatic amputation of the distal finger has been reported in an aikido maneuver [28], and a simultaneous triple dislocation of the small finger has been described during karate practice [29]. Injuries to the fingers can occur in all settings of judo. Depending on the definition of injury used, the fingers were in some studies considered the most common injury location during competition. Pierantozzi and Muroni [3] found that in high-level competitions, most incidents were musculoskeletal stress of minor severity (55%) which is in accordance with the findings of Buschbacher et al. [24], who described that injuries to the fingers most frequently involved a sprained or “jammed” digit or a minor fracture. The former researchers [3] described that most injuries to the fingers resulted during tachi-waza (29.6%). In male judokas, the finger was the most frequently injured body part, whereas female judokas sustained predominantly injuries to the shoulders [11]. Injuries to the fingers most often resulted from grip fighting, being thrown, or attempting to throw [3, 10, 11, 30, 31]. In adult elite judokas, grip fighting has the biggest time share during the fight [32]. Only one study related specific throwing techniques to frequency of injuries to the different body parts. The ippon-seoi-nage throw was responsible for finger injuries in 19% of all injuries after shoulder injuries, accounting for 31% of the injuries. Applying the tai-otoshi throw, the fingers were found to be the third most affected body part with 14% after knee (51%) and ankle (21%) injuries. It has not been clarified if the injuries resulted in the tori or uke situation [19]. Souza et al. [10] analyzed 93 senor judokas in 110 judo events in a 1-year interval in São Paulo, finding that fingers were with 17.3% the third most frequent body part to be injured after the knee (26.3%) and the shoulder (21.8). Sprains were with eight incidences the most frequent injury type, followed by partial and total finger dislocation (three each), contusion [2], incision [1], ligament injury [1], and fracture [1]. Table 8.1 summarizes the frequency of judo injuries to the fingers during competition and training as documented in the literature.

8.8 Situations and Judo Techniques with a High Prevalence for Finger Injuries

8.8.1 Kumi-kata

The basic grip position is the sleeve/lapel grip where the judoka grips the opponent's sleeve with one hand and the opposite lapel of the judogi with the other hand (Fig. 8.3). Different standard situations arise if the judokas are using the same grip (both judo players are fighting right-handed or left-handed) or different grips (one player is fighting right-handed and the opponent left-handed). In any situation, it is necessary to fight to get to one's grip. The fingers are the first body part to make contact with the opponent. For the judoka, it is a crucial moment to achieve a good grip on the opponent's judogi allowing to perform the most suitable and effective technique. It is therefore understandable that a dispute for the best gripping is very serious and aggressive, and it is important for further actions in the standing position. Compared to younger age groups investigated (pre-juvenile, juvenile, and junior), the gripping time was clearly longer in senior players comprising 28% of combat time [32]. While younger judo players voluntarily grab the opponent's judogi and the fight is basically considered to start after the grip has been established with the focus lying on the throwing techniques, experienced judokas become more versatile in grip fighting as it may condition the further fight. Gripping seems to be one essential characteristic determining expertise in judo matches [33]. The findings of Buschbacher and Shay [24] who described that older martial artists had a higher injury rate than younger participants and advanced students had more injuries than did beginners could be explained to some extent by the longer and more intense grip fighting sequence. The judoka will first try to avoid the opponent's grip with their own hands, and the fingers may get squashed and twisted (Fig. 8.4). Axial compression can lead to finger sprain injuries by accidently hitting the straightened fingers or the thumb against the opponent's upper body while trying to establish the grip (Fig. 8.5). Jäggi et al. [34] stated that the finger joints are particularly endangered by grabbing the opponent's judogi. Common finger injuries as dislocations or sprains of the interphalangeal joints are mostly due to a wrong grip with the finger(s) blocked in the collar of the judogi [35] (Fig. 8.6). Trying to free the opponent's grip by fast rotation of the forearm (upper body) can cause the opponent's fingers to be trapped in the sleeve or the collar of the judogi, and the fingers are forced into hyperextension in opposition to active flexion (Fig. 8.7). Flexor tendon avulsions with or without bony flake fracture can be the result. By the same defense maneuver, the opponent's thumb can suffer an abduction trauma leading to partial of complete rupture of the ulnar collateral ligament of the thumb metacarpophalangeal (MCP) joint. Although direct bending of the opponent's fingers and thumb is forbidden, freeing the grip with both hands as it was allowed until the IJF rules changed in 2013, often accidently put the opponent's thumb or fingers under hyperextension stress risking capsular and ligamentous injuries and palmar plate avulsions predominantly to the MCP joints (Fig. 8.2). Another forbidden action is grasping into the opponent's sleeve. The judoka is only allowed to grasp the sleeve of the jacket on the outside, not to stick the fingers into the sleeve. However, this may

Table 8.1 Frequency of injuries in judo during competition and training with special focus on finger injuries

Study	Competition	Total injury risk (%)	Competition/ training (%)	Total finger injuries N/(%)	Sprain N/(%)	Partial dislocation N/(%)	Total dislocation N/(%)	Contusion N/(%)	Incision N/(%)	Ligament injury N/(%)	Fracture N/(%)
Souza et al. (2006) [10]	São Paulo State Championship 2005	118.3	49.1/43.6	19/17.27	8/7.27	3/2.73	3/2.73	1/1.82	1/0.91	1/0.91	1/0.91
Green et al. (2007) [11]	United Kingdom, 3 tournaments in 2005	13.5	100/0	10/10.33							
James and Pieter (2003) [26]	National Judo Tournament, United Kingdom	12.9	100/0	1/4.85							
Pierantozzi and Muroni (2009) [3]	Video analyzation of 4 international tournaments 2006/2007	28.9	100/0	8/29.6							
Kujala et al. (1995) [15]	Finland 1987–1991	117	30/70	4.5%			0.3%				18.6%
Barsottini et al. (2006) [19]	Regional competitions, Brazil 2004	83	29/71	8/10							
Yard et al. (2007) [21]	United States 1990–2003	4.8/year	–	1/1.3%							

Fig. 8.3 Grip fighting. Both judokas are gripping left with the left arm in the opponent's lapel. The judoka in the blue judogi is applying a standard grip with his right hand holding onto the opponent's left sleeve, while the judoka in white is trying to grip high and achieve a pocket grip on his opponent's back

Fig. 8.4 Grip fighting. Both judokas are blocking the grip with one hand, risking to squash and twist their fingers, while they established a good grip with the other hand. The judoka in the blue judogi has taped his right ring and little finger together to protect the collateral ligaments; his opponent has taped the distal interphalangeal joints separately to protect them from superficial lacerations and sprains

happen accidentally, and the thumb or the fingers can get trapped in the sleeve (Fig. 8.8). When the opponent is turning into a throw, this may result in minor injuries as superficial lacerations of the fingers, capsular and ligament injuries up to dislocations, and less likely finger fractures. (Fig. 8.9). Other unconventional grips as the so-called pistol grip or the pocket grip are only allowed if they lead to an immediate throwing attack according to the new IJF rules from 2017. The pistol grip does not lead to an increased risk of injury but grants an illegal advantage of control to the tori (Fig. 8.10). The "pocket grip," where one judoka rolls his fingers into the sleeve or back of the opponent's judogi, also provides tori an advantage as he dominates the situation by controlling and directing uke's arm much better than by the normal grip (Fig. 8.11).

Fig. 8.5 Grip fighting. The judoka wearing the white judogi is jamming his thumb and index and middle finger at his opponent's chest while trying to achieve a good grip on the lapel. Sprain injuries or fractures through axial compression may result

Fig. 8.6 The judoka wearing blue has blocked the fingers of her left hand in the opponent's judogi. When the opponent will try to free the grip or turn into a throw, her fingers are at risk for sprain injuries to the trapped interphalangeal joints

8.8.2 Nage-Waza

8.8.2.1 Injuries to Uke While Being Thrown

Miarka et al. [32] showed that the average standing combat time comprised 46% in senior judo players. Injuries affecting the fingers fighting in the upright position most commonly affect uke resulting from being thrown onto the mat by tori. Those are direct traumata and often provoke sprains and sub-wrenching. Direct impact by falling on the mat may also lead to finger dislocations or fractures. The first thing that is taught when starting to practice judo is how to break a fall (ukemi). A poorly executed breakfall is a common source of injury [36]. It is therefore imperative to master the technique of falling safely. When falling, one should hit the mat hard with one or both

Fig. 8.7 The judoka in the blue judogi is trying to escape from his opponent's grip by fast rotational upper body movements and ripping his own judogi away. His opponent's fingers are subjected to hyperextension in the interphalangeal joints in opposition to active flexion, thus risking injuries to the flexor tendons or the pulley system

Fig. 8.8 The left thumb of the fighter wearing blue is trapped in the opponent's left sleeve

extended arms and the palmar ulnar aspect of the hand with a sideway sliding movement to absorb the impact while tucking in the chin to prevent hitting the head on the mat. Beginners, who are not familiar with ukemi, may hit the mat too directly with the ulnar boarder of the hand, or this may be the result of preventing to fall onto the back in order not to lose a fight, and the fifth metacarpal bone as well as the phalanges of the little finger becomes susceptible to fractures (Fig. 8.12). Experienced judokas try to avoid being thrown during randori and competition and often land on the outstretched hand to prevent landing on their back and risking to lose the fight (Fig. 8.13). Finger fractures or finger dislocations may result from direct impact on the mat, while strain injuries to the fingers commonly occur if the judo player is trying to escape from the throw [11].

Fig. 8.9 The fingers of tori and uke are trapped in the opponent's sleeve

Fig. 8.10 Pistol grip. No direct injury risk results from this grip, but it is only allowed if an immediate throwing action follows

Fig. 8.11 Pocket grip. The dorsal aspect of the fingers is subjected to friction injuries on the rough material of the judogi

8.8.2.2 Injuries to Tori While Throwing

The judoka performing the throw is not immune against injuries [36]. Green et al. [11] found that strain injuries commonly occur when attempting to throw. Throwing consists of three phases. The first part is kuzushi; it is breaking an opponent's balance by pushing and pulling, thus exposing the fingers to friction injuries at the rough material of the judogi (Fig. 8.14). The second part is tsukuri, the act of turning into the throw, risking the fingers to be twisted and entangled in the judogi (Fig. 8.15). The last part of a throw is kake, the execution and completion of the throw (Fig. 8.16). Often a throw is not completed under perfect control and uke may fall on top of tori or vice versa. Especially in techniques where tori holds onto uke's belt or puts one arm around the opponent's back, his hand will be susceptible to injuries because the hand may be squashed between the mat and uke's back (Fig. 8.17).

Fig. 8.12 Uke (white judogi) is avoiding a proper breakfall and landing onto her back while being thrown. She hits the mat with the ulnar rays of her hand risking fractures of the metacarpal and phalangeal bones through direct impact

Fig. 8.13 Uke (in blue) is trying to escape from the throw—he will land onto his outstretched left hand. Tori (in white) is grabbing his opponent's judogi on the back at the level of the belt with a pocket grip

8.8.3 Te-Waza

Te-waza are the hand techniques from the group of the nage-waza (throwing techniques).

There are 15 traditional te-waza listed in the Kodokan judo of which many variations exist. They consist of effectively using the hands, arms, and shoulders to throw the opponent. It is obvious that te-waza particularly put tori at risk for injuries to the fingers.

8.8.3.1 Seoi-Nage (Shoulder Throw)

The seoi-nage is one of the first throws being taught in judo. It is a perfect example of applying the judo philosophy "softness defeats hardness" as it allows small judokas to throw a larger opponent (Fig. 8.18). The seoi-nage is not the easiest throw but very effective and a popular technique through which many competitions are won. It is a very colorful technique and numerous variations have been developed.

Fig. 8.14 Kuzushi. The judoka in blue is pulling and breaking the opponent's balance before turning into the throw, exposing her fingers to friction on the opponent's judogi

Fig. 8.15 Tsukuri. The judoka in blue turned into the throw (tai-otoshi). His right-hand fingers are entangled in the opponent's lapel and subject to distortion

Miarka et al. [32] mentioned that especially the ippon-seoi-nage accounted for a high incidence in finger injuries. However, in this study, it has not been differentiated to which percentage the injuries affected tori and uke. When both fighters are right-handed, tori grips uke's right jacket sleeve with his left hand; uke's right upper arm is wedged in by tori's right elbow. Uke is then pulled onto tori's back and flipped over by a strong diagonal down-pull of his left hand and rotation of the upper body. The authors therefore believe that injury to tori's fingers is less likely in ippon-seoi-nage as only one hand is pulling the judogi and that injuries to uke's fingers may

Fig. 8.16 Kake. The judoka in blue is throwing her opponent in a tai-otoshi variant. She has applied a pocket grip on her opponent's back, throwing her opponent mainly with both hands by pulling strongly down and flipping her over her leg

Fig. 8.17 The judoka in white achieved an ippon by throwing his opponent onto the back. His hand is squashed between the mat and his opponent's back

occur by falling as the arm is better fixed and evasive movements during the throw more difficult. In our opinion, the variant morote-seoi-nage puts tori under a higher risk of suffering a finger injury. In this technique, the breaking of the balance is performed as in the original version, and then tori's one hand pulls the sleeve of the opponent while the elbow of tori's other hand is passing under uke's shoulder ideally so that the distal forearm or hand comes to rest in uke's armpit (Fig. 8.19). The throw is then accomplished as described above. When the throw cannot be executed perfectly and uke's balance cannot be broken, uke leans backward and thus forces tori's fingers of the right hand under extension stress. Uke's balance may be broken, but tori may not be able to turn uke so tori may hit into the mat, and uke on top of him may crush tori's fingers of his right hand between tori's back and uke's chest.

Fig. 8.18 End phase of a seoi-nage (shoulder throw)

Fig. 8.19 Morote-seoi-nage. Tori's right hand tucked in under uke's armpit making is susceptible to injuries during the end phase of the throw as the hand is fixed. Uke is trying to prevent being thrown on his back with his outstretched left hand

8.8.3.2 Tai-Otoshi (Body Drop)

Another classical judo throw is the tai-otoshi. Although uke will be thrown over tori's blocking leg, it is still considered a te-waza. The essence of an effective tai-otoshi lies in the throwing action as directed by the hands. In strong tai-otoshi attacks, even when the defender manages to step over the thrower's outstretched leg, he still gets thrown by the turning action of the hands (Figs. 8.15 and 8.20). Tai-otoshi has been found to be the second common throw leading to finger injuries after seoi-nage [32]. As in other nage-waza, many different variations of tai-otoshi exist. Throwing techniques were modified as answers to difficult situations, awkward grips, and power. It is, e.g., difficult to perform a traditional tai-otoshi if the opponent is gripping differently (right-handed against left-handed judo players). Being a te-waza, it is utmost important to impose one's grip on the opponent. For a basic

Fig. 8.20 Tai-otoshi. A classical hand technique. Tori (in blue) is pulling down with both hands and flipping uke over

tai-otoshi, a right-handed fighter will hold the opponent's right sleeve at the elbow level with his left hand and uke's lapel high up with his right hand. For breaking the balance, tori will then pull hard with his left hand, then pulling himself into uke using both hands, placing the right leg in front of uke, and pulling down strongly with both arms to flick uke over the straightened leg.

8.8.4 Katame-Waza

Though less frequently also during katame-waza, mechanisms of injury are encountered [23]. Miarka et al. [32] found that groundwork accounted for 15% of all injuries during a fight. Also during ground fighting, the fingers can become entangled and trapped in the sleeve or the lapel of the judogi. Most injuries to the fingers during fighting on the ground occur to uke. When a judoka is trying to apply a choking technique, he is trying to get his fingers high up in the collar of the opponent close to the neck with one or two hands or use the opponent's collar to apply the choke. Uke will try to avoid this by protecting his neck often with a cross grip in his own judogi. Tori will then try to remove uke's hands or vice versa. Although direct grabbing of single fingers and deliberate twisting of the opponent's fingers leading to hyperextension and distortion are not allowed, direct contact to the opponent's hand and trying to push the hand away conform with the rules (Fig. 8.21).

When trying to apply an armlocking technique, uke is desperate to hold onto his own judogi or his other hand and not to let go of his arm, while tori will try to free and extend uke's arm to apply, e.g., a juji-gatame (cross armlock), one of the most efficient and popular armlocking techniques through which many fights are won on the ground. As seen in Fig. 8.22, tori is trying to straighten his opponent's arm and uses his upper body as a leverage, while uke only relies on his finger grip on his own judogi. Through unequal forces of the upper body combined with the right lever techniques, uke's grip often cannot withstand the attack, and he is forced to let go of his grip. During the crucial time while tori is trying to get hold of uke's arm, the fingers are exposed to raw forces, and flexor tendons, ligaments of the interphalangeal joints, and the joint capsule are at risk to suffer injuries. While the force is applied gradually, the impact is usually not as abrupt as in faster actions in tachi-waza. Injuries therefore are more caused by overstraining and will occur to the weakest structure. Even fractures to the finger

Fig. 8.21 Okuri-eri-jime (sliding collar lock). Uke (in white) is trying to defend a strangulation technique by pulling down tori's right arm with both hands which is allowed in ground techniques. Tori's fingers may be bent and twisted

Fig. 8.22 The judoka in blue is trying to straighten his opponent's arm and apply a juji-gatame (cross armlock). Uke (in white) is protecting by holding onto his right lapel

may occur during ground fighting when the soft tissue structures are stronger.

When trying to apply a holding technique, uke usually needs to be turned onto his or her back first. This is frequently achieved by grabbing the opponent's judogi—also grabbing of the pants is allowed in katame-waza—and performing special turning movements. While trying to turn the opponent or escaping from a holding technique, the fingers often get entangled and twisted in the judogi being prone to sprain injuries to the fingers. Again, by holding onto the opponent's pants, there is a mismatch in force of the muscles of the leg and muscles/tendons of the arm/fingers subjecting the tendons to disproportional stress (Fig. 8.23).

Fig. 8.23 The judoka in blue is applying a holding technique, while uke (in white) is trying to turn his opponent around and free himself. The fingers of both judokas are exposed to friction forces and can get entangled in the judogi

8.9 Injury Patterns to the Fingers

The most frequent finger injuries are skin abrasions on epidermal level, sprains, and strains followed by partial or total finger dislocation, ligament and tendon injuries, and fractures.

8.9.1 Skin Abrasions

Contact sports as judo involve close physical contact between the opponents and injuries as skin abrasions arise generally from constantly rubbing the knuckles against the heavy and structured judo jacket. They are mainly injuries on epidermal level (Fig. 8.24).

8.9.2 Skin Infections

Superficial skin lesions as abrasions combined with sweating and continuous rubbing of the skin are factors that increase the likelihood of transfer of infectious agents and are by their nature at risk for skin infections [37]. In judo, the exposed extremities and especially the fingers are very susceptible for superficial lacerations. Skin abrasions on the fingers are very frequent minor injuries that occur regularly during training or competition. The fingers grip the judo jacket, which consists of a rough and woven cotton, and are exposed to constant friction as the opponent will try to loosen the grip. This is often achieved with pushing down the opponent's hand (Fig. 8.25). Another method also to gain distance is to perform an abrupt movement backward (Fig. 8.26) or combined with rotation of the upper body to

Fig. 8.24 Superficial skin lesion on the dorsal aspect over the distal interphalangeal joint of the right middle finger and the left index and middle finger

Fig. 8.25 Freeing the grip by pushing down the opponent's hand and exposing the opponent's finger to friction on the judogi becoming susceptible to superficial skin lesions. For prevention, the distal interphalangeal joints that are predominantly subject to epidermal lesions are taped

Fig. 8.26 By moving backward, the judoka in blue will not be able to loosen her opponent's strong grip. She will need to hold onto her own lapel and wrest herself free

free oneself from the opponent's grip (Fig. 8.7). The judoka having a good grip will try to keep the grip—exposing his fingers, especially the dorsal aspect of the distal interphalangeal joints, to friction and twisting forces. Constant rubbing of the skin of the dorsal aspect of the distal interphalangeal (DIP) joints often leads to superficial abrasions (Fig. 8.24). Although skin abrasions are frequent, serious infections do not seem to be frequently observed. From our personal experience, superficial skin infections that occurred over the DIP joints after a laceration were treated with local measures as immobilization, disinfection, and antibiotic therapy without the need of further surgical intervention or resulting complication. Despite personal experience, no case of infections resulting from skin injuries in judo has been published to our knowledge. Any abrasion, skin laceration, open sore, or cut can serve as an entry portal for bacterial, fungal, or viral agents and cause skin and soft tissue infections. In judo, a local abscess or if more severe a lymphangitis or phlegmon is the most likely infection. Next to preventive measures as taping at the level of the interphalangeal joints, more over the distal interphalangeal joint, appropriate treatment of

Fig. 8.27 The top right and top middle picture is the clinical presentation of a 27-year-old elite judoka who sustained a sprain and hyperextension to his right middle finger PIP joint with swelling and restricted flexion joint during grip fighting. RX on the top right and the ultrasound image on the bottom confirm a palmar plate avulsion

the seemingly irrelevant lacerations is essential. Hygienic principles, including wound cleansing and bandaging, should be followed to help prevent the infection [37].

8.9.3 Sprains and Strains

One of the mostly encountered finger injuries in judo is sprains and strains. The fingers are constantly subjected to pulling forces while holding onto the opponent's judogi by attacking or defending. Starting with kumi-kata, the fingers crush against the opponent's finger and may suffer axial trauma by accidently jamming the finger into the opponent while trying to grip the opponent's lapel (Fig. 8.5). While throwing and being thrown, the fingers can be trapped and twisted in the lapel and sleeve of the judogi (Fig. 8.9). In any situation on the ground, while trying to turn the opponent or carrying through a choking technique or armlocking technique, the fingers also may get entangled in the judogi during attacking and defensive maneuvers, and the finger joints, especially the proximal interphalangeal (PIP) joints and the DIP joints, are prone to sprain injuries (Fig. 8.23). Diagnosis is made clinically—usually pain and swelling prevail—and primary medical treatment, if necessary, consists of cooling, resting, and splinting. Professional medical attention is usually reserved for more severe sprains. Fractures are excluded and articular anatomy evaluated by X-ray. Soft tissue injuries as palmar plate avulsions or tendon ruptures are diagnosed by ultrasound or MRI (Fig. 8.27). Preventive measures mainly constitute of tapping the interphalangeal joint for stabilization. Special enforcement training to strengthen the grip power may be helpful in preventing sprain injuries. However, repetitive microtrauma and overuse damage to the finger joints especially in elite judoka and also recreational judokas with long-standing judo practice are unavoidable and predispose for the development of finger polyarthrosis.

8.9.4 Traumatic Finger Polyarthrosis

Overuse and repetitive injuries to the finger joints due to extensive judo training may play an important pathogenetic role in the development of osteoarthritis of the DIP and PIP joints. Frey and Müller [30] observed the increased occurrence of Heberden's nodes in 9 out of 30 judo practitioners of the Swiss national team on several fingers. Furthermore, all 30 judo players showed clinical and radiographic signs of arthrosis of the PIP joints as axial deviation, extension deficit, and some joint space narrowing. However, the radiographic changes have been described to be very moderate in comparison to the clinical manifestation. Out of 100 male control judo players not practicing on an elite competition level, no Heberden's nodes or Bouchard's arthrosis was noted. All athletes affirmed finger distortion injuries, sometimes with a history of extensor tendon injuries. On interrogation, the judoka with Heberden's nodes seemed to prefer to grip the opponent's judogi sleeve with one hand, while the ones without Heberden's nodes preferred the grip on both collars. Additionally, the use of raw power (e.g., in not letting go of the grip of the judogi if the opponent is trying to free himself) and more ground techniques seemed to be negative factors for the development of finger polyarthrosis. Eight of the judo players presenting with Heberden's nodes were followed several years later by Strasser et al. [31], showing the persisting Heberden's nodes also in judokas who were not actively practicing judo anymore. This suggests that also Heberden's nodes without serious changes on the X-ray are permanent lesions. On the other hand, the degenerative changes were shown to be progressive and more pronounced in still active players. Bahr [38] also emphasized that overuse injuries may represent as much of a problem as do acute injuries. Despite the clinically severe finger deformation, in some cases the individuals are not relevantly impaired during judo training, competition, their work, or daily activities; thus, medical attention is usually not sought. Overuse injuries are seldom properly registered and documented, and the current standard epidemiological methodology is especially inadequate for that documentation [38, 39]. Additional known risk factors for the development of osteoarthrosis as familial predisposition, age, and hormonal status do not seem to play a significant role for the development of osteoarthrosis in active judo players. On interrogation and clinical examination of judo athletes of the Hamburg Judo Team (HJT) competing on national and international level, almost every athlete presented with at least one chronic finger deformity of the DIP or PIP joints (Figs. 8.28a, b and 8.29a–c). Prevention of overusing the finger joints in judo players is almost impossible as judo is a contact

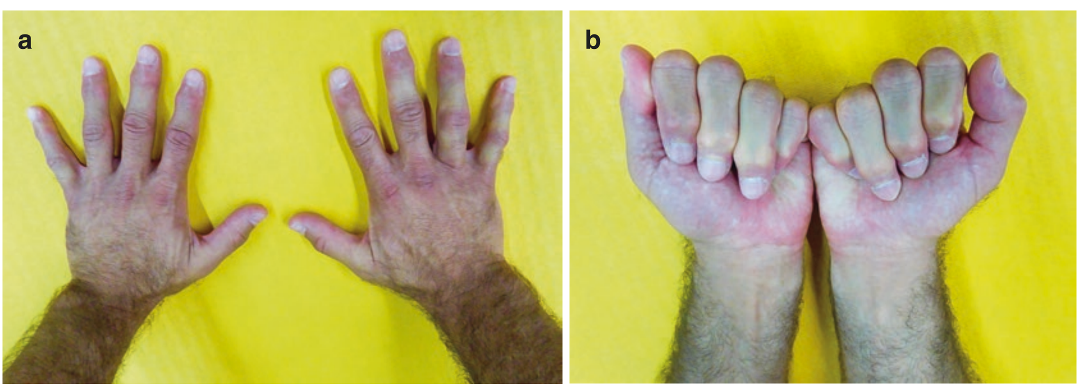

Fig. 8.28 (**a**, **b**) Clinical presentation of the fingers of a 41-year-old judoka who has been practicing judo on national and international level for over 20 years. He shows chronic capsular injuries with deformation of several distal and proximal interphalangeal joints. The flexion is slightly impaired especially at the distal interphalangeal (DIP) joints with otherwise good and pain-free finger function

Fig. 8.29 (**a**–**c**) Clinical and radiographic presentation of a 25-year-old judoka competing on international level over several years. Obvious Heberden's nodes are present on all DIP joints and osteoarthosis confirmed on the DIP joint of his left ring finger. Repetitive capsular injuries also occurred to his proximal interphalangeal (PIP) joints with slightly reduced flexion for the ring finger

sport and it is mandatory to grip the opponent's judogi to perform a throwing or a ground technique. The fact that only elite judoka, competing on a high level, seems to be prone to chronic overuse finger joint injuries indicates the correlation with intensive grip fighting as a major contributor. Senior experts have a higher rate of technical and tactic gripping knowledge and spend more time on grip fighting than junior athletes or recreational judoka [32]. Prevention of repetitive microtrauma can be achieved by taping the distal interphalangeal joints, thus preventing friction and direct exposure with the rough judo jacket. The aim is to prevent minor acute injuries. Taping fingers together prevents ligament or capsular stress as seen on most fighting pictures (Figs. 8.4, 8.16, 8.22, and 8.25).

8.9.5 Rupture of the Ulnar Collateral Ligament (UCL) of the Thumb MCP Joint

Hyper-abduction and tearing or rupture of the medial collateral ligament of the thumb MCP joint provoked by hyper-abduction has been reported [40]. This injury is most likely to occur to the judoka having his grip on the opponent's judogi while the opponent is trying to free the grip with the hand, through quick and twisting body movements (Figs. 8.2 and 8.7), or while fighting on the ground.

An instable UCL of the thumb MCP joint is diagnosed by clinical examination, and radiographic evaluation should rule out osseous lesions. An ultrasound or MRI should be carried out to exclude Stener's lesions in which case surgical refixation is inevitable (Fig. 8.30). Conservative treatment consists of 6 weeks of immobilization in a thumb spica thermoplastic splint.

8.9.6 Hyperextension Injuries

Hyperextension mainly to the MCP joints of the fingers can occur during a fall on the outstretched hand avoiding being thrown onto the back. Tori's throwing action is often a dynamic rotating movement that is transferred to uke. After uke is avoiding a breakfall on the mat with his hand on the mat, the twisting movement of the throw is continued, and uke and tori roll over uke's extended fingers provoking a hyperextension force on the MCP joints (Fig. 8.31). Another mechanism of hyperextension injury is also the abrupt twisting movement of the opponent when he is trying to free the attacker's grip on the lapel forcing the fingers into hyperextension (Fig. 8.7). Lesions to the structures on the palmar aspect of the fingers may be the result as palmar plate avulsions, flexor tendon injuries, injuries to the annular ligaments, and the collateral ligaments. Diagnosis is made clinically and by ultrasound to exclude instable collateral ligament injuries.

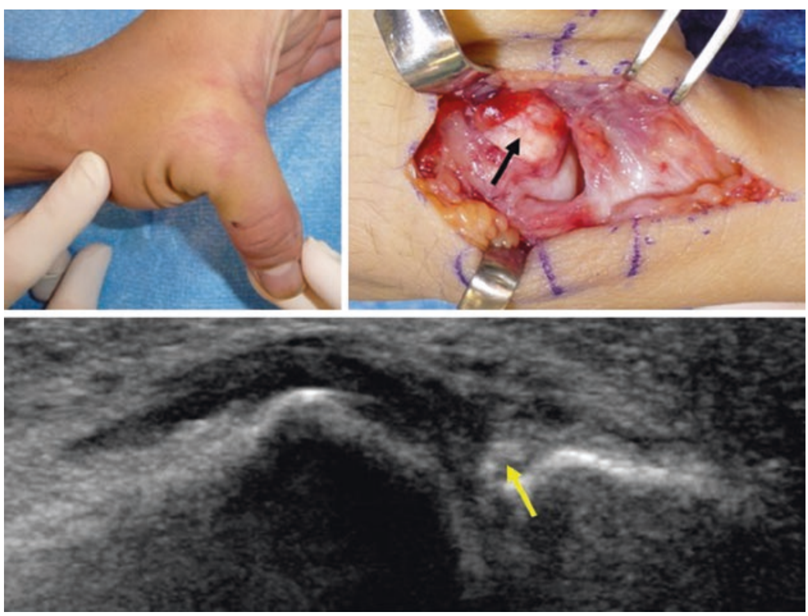

Fig. 8.30 The top left picture shows the clinical presentation of an instable ulnar collateral ligament of the thumb MCP joint. The bottom picture shows the ultrasound image with avulsion of the ligament from its insertion on the base of the proximal phalanx (yellow arrow). The top right picture shows the intraoperative findings with typical Stener's lesions—the UCL is flipped back (black arrow) and comes to lie superficial to the aponeurosis of the adductor muscle of the thumb

Fig. 8.31 Uke's fingers of his right hand are exposed to hyperextension forces, while tori (in blue) is finalizing a shoulder throw

Fig. 8.32 Clinical presentation of a swollen left hand of a judoka after hyperextension of the MCP joints from being thrown

Regarding the MCP joints, a swelling with pain predominates clinically (Fig. 8.32). Hyperextension injuries to the PIP joints are also diagnosed clinically and by ultrasound (Fig. 8.27). Further evaluation with an MRI or CT scan is rarely indicated and reserved for complex cases and for the evaluation of intra-articular fractures. Palmar plate lesions and most collateral ligament lesions should be treated functionally with free range of motion in proportion to the pain along with anti-inflammatory, decongestant measures and hand therapy. Training can be resumed after a few weeks with protective soft splinting. In the case of injuries to the A2 or A4 pulley, conservative treatment as special thermoplastic ring splints for 8 weeks followed by therapeutic and preventive imbricating taping is important. If not diagnosed and treated immediately, finger flexion contractures with loss of range of movement and grip power may be the result and surgical reconstruction of the insufficient A2 pulley indicated (Fig. 8.33).

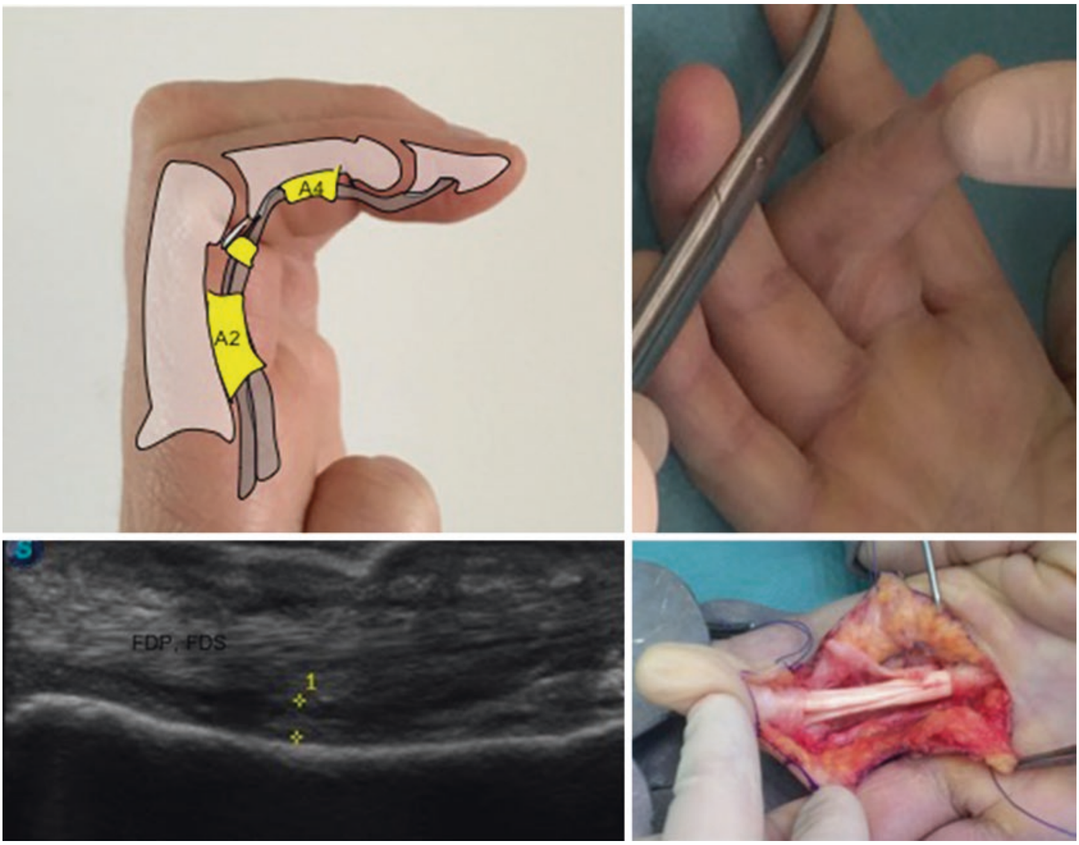

Fig. 8.33 On the top left, a schematic illustration of the pulley system and the flexor tendons is shown. On the top right, a 3-month-old A2 pulley lesion with a 70° flexion contracture is shown. The ultrasound on the bottom left shows the space between the proximal phalanx and the flexor tendons of 4 mm due to a ruptured A2 pulley. The bottom right is the intraoperative finding with the torn and insufficient A2 pulley. Reconstruction was needed

Surgical refixation of the collateral ligaments of the MCP joints other than the thumb is rarely indicated. However, pain and swelling often persist for a long period in serious hyperextension injuries.

8.9.7 Finger Flexor Tendon Avulsion Injuries

Finger flexor tendon avulsion injuries with or without osseous flake avulsion derive predominantly from kumi-kata and turning into the throw. More precisely, the judo player who already has a grip on the lapel or the opponent's judogi is at risk. His distal and proximal interphalangeal joints are flexed around the collar of the judogi jacket, and a high amount of tension force is applied to the flexor tendons as he is trying to pull the opponent toward him and turning into the throw. The opponent will try to break the grip by abrupt twisting movements, thus applying an extension force to the finger joints of his opponent who is holding the lapel of the judogi and trying to block and gain distance. When tori has already turned into the throw, the opponent will try to block and lean backward or perform a counter-attack (Fig. 8.34). With the jerky extension of the finger joints, the flexor tendon is at risk to rupture at its insertion. Special enforcement training of the flexor tendons as practiced by professional rock climbers may be beneficial. The detailed injury mechanism is described in Chap. 6 of this book.

Fig. 8.34 Blocking a throw/counter-attack from the judoka in blue forcing his opponent's fingers into extension which puts them at risk for flexor tendon avulsion injuries

Fig. 8.35 Clinical presentation of an extensor tendon avulsion at the DIP joint. Radiographic imaging shows an osseous avulsion on the top right. Treatment consists of thermoplastic splinting as shown on the bottom right which is not allowed to be worn during judo practice. Taping is often not sufficient

8.9.8 Extensor Tendon Injuries

Rupture of the conjoined extensor tendon at the insertion of the dorsal aspect of the distal phalanx happens frequently when the fingers are getting caught in any part of one's own or the opponent's judogi. Although considered, a minor injury adequate splinting for 8 weeks in a thermoplastic splint that is not allowed to be worn during judo practice or competition, as any hard object may inflict pain and damage to the opponent, is essential (Fig. 8.35). Normal training should be resumed only after 3 months when the scar tissue is strong enough to withstand the forces applied to the tendons during judo. Closed ruptures of the extensor tendons more proximally are less frequently observed. Next to the clinical assessment, ultrasound diagnostic is reliable and objectifies the diagnosis especially in cases of partial rupture [41].

Depending on the extent of the tendon lesion, surgical treatment may be necessary with a general training break of 3 months.

8.9.9 Finger Dislocations

Dislocation of the fingers may affect any finger joint, the MCP, PIP, or DIP joint. Injury mechanisms are the same as described above for sprain injuries with more force involved, as a result of direct impact on the mat or hyperextension during a fall. Most frequently, the PIP joint is affected resulting in a subluxation or luxation. The dislocation can happen in any direction, but dorsal dislocations or dorsolateral dislocations are encountered predominantly. Closed reduction with or without local anesthesia after ruling out concomitant fractures is usually achieved. The structure injured most frequently in dorsal dislocations is the palmar plate, but concomitant lesions to the collateral ligaments may be present. If the joint remains stable after reduction, functional mobilization with buddy taping of the finger to the next finger is suitable (Figs. 8.14, 8.22, and 8.36). In case of persisting instability after successful joint reduction, thermoplastic splinting may be necessary to prevent shear stress. Conservative treatment is usually sufficient and surgical interventions only reserved for persisting severe instability or palmar dislocations with avulsion of the central tendon slip at the dorsal aspect of the base of the middle phalanx.

Fig. 8.36 Dorso-ulnar finger dislocation of the middle finger PIP joint. Ultrasound shows a thickening of the ulnar collateral ligament in accordance with a mid-substance tear. After reduction, the joint remained stable, and functional treatment with buddy taping was sufficient

8.9.10 Fractures

Fractures of the phalanges in judo occur mainly while being thrown through direct impact onto the mat or by grappling. In beginners and younger judoka, poorly executed break with landing on the outstretched hand can result in metacarpal or finger fractures, affecting mostly the ulnar rays, the fourth and fifth finger (Fig. 8.12). Fractures were observed more frequently in children than in adults [22] (Fig. 8.37). Approximately 25% of all injuries presenting to the pediatric emergency department are fractures and physeal injuries [21]. Judo players who try to avoid a proper breakfall as this may result in losing the fight are also at risk for fracturing a phalangeal bone. Also tori is susceptible to finger fractures, e.g., when he has his hand on the back of uke's judogi or is holding onto uke's belt and throws uke backward, thus crushing his fingers between the mat and uke (Fig. 8.17). The quality of the judo mat which is absorbing the fall also plays a role in the occurrence of finger fractures. Mats not providing enough impact protection and being too firm constitute an additional risk factor for fractures. Diagnosis is usually made clinically as typical symptoms like swelling, bruising, pain with or without axial deviation, or rotation deformity are present. Radiographs in two planes confirm the clinical diagnosis. Only for some intra-articular fractures, especially die-punch fractures (Fig. 8.38), further imaging with an MRI or CT scan may be necessary. Pediatric finger fractures heal faster than adult finger fractures, and immobilization time is shorter [42]. In cases where rotational or axial malalignment cannot be corrected by conservative measures, surgery may be warranted (Fig. 8.39). Physeal injuries may lead to an impaired phalangeal growth leading to finger deviation or premature fusion of the growth plate. Hand surgeons specialized in pediatric hand surgery should be consulted.

8.10 Prevention

Considering the relatively high frequency of upper limb injuries and especially finger injuries resulting from being thrown in judo, meticulous breakfall training, avoiding to fall on the hyperextended fingers, is essential. Badly executed throws can also cause injury to the attacker via dropping the competitor on themselves or performing a sutemi-waza [43]. It therefore is very important for instructors to ensure that judokas new to the sport learn how to break a fall and to teach the throwing techniques under constant correction and supervision. It may take a long

Fig. 8.37 Children at a judo tournament. By improper breakfalls while avoiding to land on one's back and landing on the hand, uke is at risk to fracture the metacarpal or phalangeal bones

Fig. 8.38 Radiographic images of a 24-year-old judoka before and after surgical treatment of a combined intra-articular injury of the DIP and PIP joint from axial impact on the mat. At the DIP joint, there is an intra-articular fracture of the base of the distal phalanx in the sense of a large osseous mallet lesion. On the level of the PIP joint, we find a central die-punch fracture on the base of the middle phalanx with dorsal subluxation (right picture). The middle picture shows the situation after surgical treatment with screw fixation of the end phalanx and extension block pinning after reduction of the PIP joint. The small die-punch fragment was left alone. The right picture shows the radiographic result 4 months after the initial injury with a stabile PIP joint and healed fracture. Full function was achieved clinically

time depending on one's physical capability before complex maneuvers are mastered and a throw is performed safely and fully controlled. Redundant practice of falling and throwing should help to prevent injuries as the techniques become more controlled and automatized [44]. However, in unforeseen randori or competitions where each situation is unique and different regarding the opponent's stature and his techniques, it is not assured that the so often-practiced throw and fall can be transferred to that specific situation [45]. In a standard training setting, the judoka would be more likely to perform a good fall and respect the opponent's throw, while in a tournament, the judoka will most likely try to prevent to fall onto the back. He is tempted to parry the throw by landing on the outstretched hand not risking to lose the fight before the end of the official fighting time. Balance training also may be useful in reducing the risk of falls.

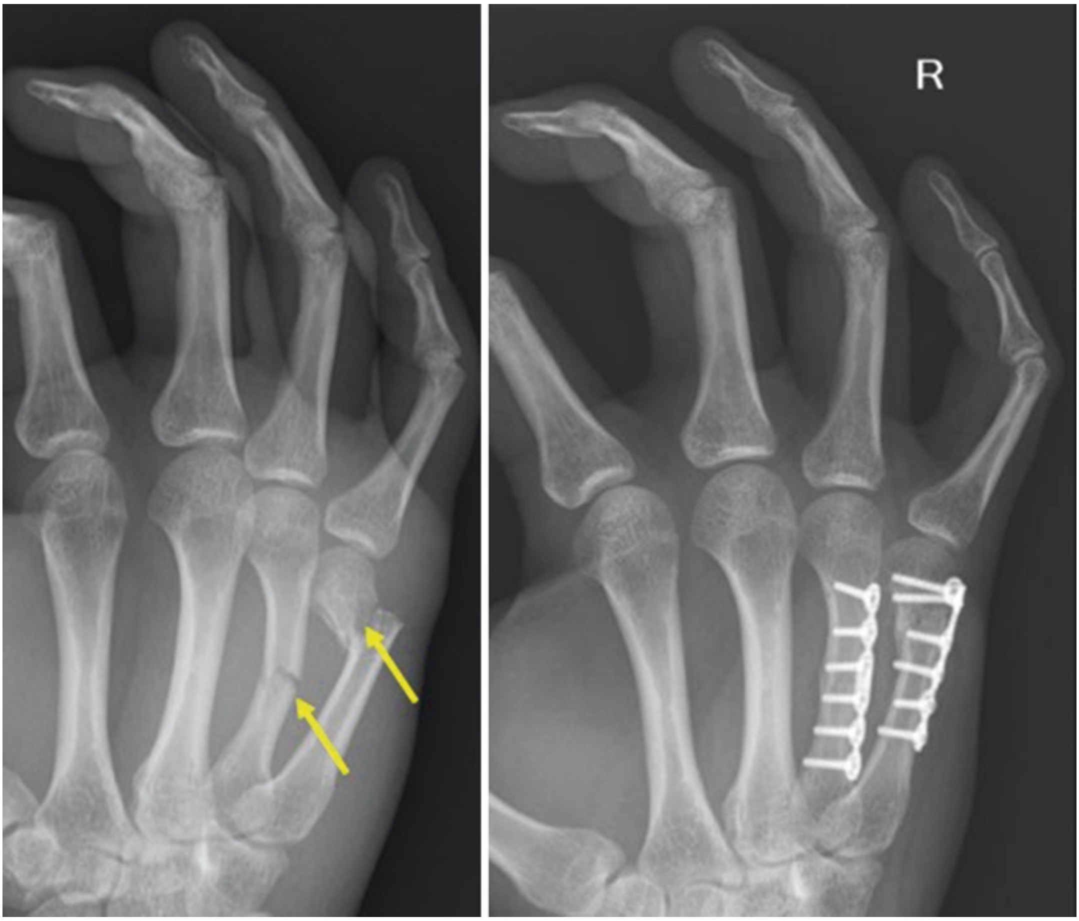

Fig. 8.39 Radiographic images before (left) and after (right) surgical treatment of metacarpal fractures of the fourth and fifth ray resulting from improper breakfall. Three months after surgical intervention, the fractures were consolidated with recovered full function

Further, the quality of the mat plays a role in influencing finger injuries from falling. Impact heights are possible up to 2 meters. A high-quality mat should be the standard for competitions and ideally also for regular judo practice. The mat needs to provide a finely adjusted balance between a firm surface, so that the athletes do not sink into it during combat, and impact protection. Faulty materials on judo mats can have the worst possible effects. Judo competitions are usually not carried out in a dojo but a public sports hall that should have a surface-elastic sprung floor to buffer the falls additionally to the judo mats. Considering the abovementioned physical and mental requirements for judo, also judo-unspecific training of strength, flexibility, coordination, conditioning, and endurance may have a positive influence on lowering the injury rate. In a judo fight, the judoka has to react to constant modifications of posture, support, ground and partner contact, musculoskeletal tension, articular angles, and joint positions [2]. He depends highly on a functioning proprioception which contributes to the neuromuscular control required for precision and reflex movements, providing joint stability [46]. Regular proprioceptive training therefore helps in injury prevention. Warming up and proper stretching is generally acknowledged to reduce especially injuries to the muscles and tendons [47]. However, in contrast to other warm-up programs as in the FIFA 11+ warm-up program, no specific programs for injury prevention have been postulated in judo and other martial arts [34]. Although nutrition, hydration, and losing weight before a competition are considered important injury risk factors in combat sports, specific research on judo is scarce [48]. Losing a small amount of body weight does not seem to predispose to injury, but losing more than 5% of body weight within a short time has been shown to increase the general risk of injuries [11, 48]. No specific attention on finger injuries following rapid weight loss has been paid. Concerning grip fighting, the international judo rules have been changed in 2013 and were valid until 2016. Up to date, no data is available to prove whether reduction of finger injuries has been achieved by those measures. Since the beginning of 2017, new IJF rules have been established and are under a trial period until the judo world championship in summer 2017. The judogi should always be clean and not smelly and meet the hygienic standards, thus reducing the risk of infections of superficial wounds on the fingers. Taping with special focus on the DIP joints is a simple measure to successfully prevent skin lacerations as well as sprain lesions. Buddy taping of the fingers to the adjacent fingers is effective in preventing distortion and protecting the collateral ligaments (Figs. 8.4, 8.14, 8.22, and 8.25). When fresh skin lesions and bleeding occur, immediate disinfection and cover with appropriate bandages or tape are mandatory for continuing the training or competition. Equally important as the physical training, it is to cultivate moral and mental fortitude according to Kano's philosophy of judo. The opponent judoka should always be treated with courtesy and respect. Deliberately inflicting pain and putting the opponent or oneself into dangerous situations thus risking injuries are not in accordance with the spirit of judo.

8.11 Summary

Every sport has its specific injury profile. Judo is a combat sport revealing a high risk to injuries and in particular finger injuries through direct contact with the opponent during grip fight, while throwing or being thrown, as well as in grabbling techniques. Finger injuries are encountered frequently in both, during training and competition; the vast majority of injuries are of minor severity as superficial lacerations, sprains, and strains and do not require medical treatment. As sprains are encountered often, it is important not to overlook injuries that are primarily not as obvious like ligament injuries or injuries to the pulley system which may have a devastating long-term result like uncorrectable flexion contractures. Functional treatment with rapid movement following dislocations and fractures should be aimed at if feasible to allow early movement and prevent a decreased range of motion. Hand therapy should be initiated whenever sensible. Although acute injuries may predominate, repetitive trauma and overuse injuries of the finger joints are frequently found. Heberden's nodes and Bouchard's arthrosis are common on the hands of middle-aged judo players who have been practicing judo for many years but do usually not lead to restrictions in practicing judo or daily life activities. More studies and better documentation are needed to evaluate especially injuries sustained during training and compare them to those sustained in competition.

Injuries can be prevented by regular training of falling and throwing and by building up physical and mental strength. The final aim of judo practice is to convey respect for the two principles of judo: maximum-efficient use of body and mind and mutual welfare and benefit. Bearing those principles in mind, injuries may be widely prevented.

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9 Degenerative Changing in Digits of Brazilian Jiujitsu Fighter

Gustavo Ruggiero Mantovani

9.1 Introduction

9.1.1 Brazilian Jiujitsu History

Brazilian jiujitsu is a martial art evolved from judo. It means, in Japanese words, the "fine art" or "smooth art." The origins come from ancient Kodokan Judo, created on 1882, by master Jigoro Kano at Japan, and then influenced by the style Fusen Ryu, on 1900, from master Mataemon Tanabe. The real story begins with a prodigy student of Jigoro Kano, named Mitsuyo Maeda (1878–1941), who was sent around the world to spread the message of the Kodokan Judo, fighting in many countries against most different fighting styles, on the so-called no-holds-barred (NHB) matches. Throughout his career as a professional fighter, after engaging in over 1000 free fights, Maeda retired without ever losing a match.

His extensive combat experience against all types of fighters resulted in a realistic, street effective method of fighting.

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During his travels, Maeda fought in the continental Europe, Great Britain, the USA, Mexico, Cuba, and finally Brazil, where he founded a jiujitsu academy on Belem, Para state, at the Amazon area.

One of Maeda's students was a young Brazilian man named Carlos Gracie, studying several years during the 1920s.

Carlos opened his own academy in 1925 on Rio de Janeiro. He and his brothers established a solid reputation by issuing the known "Gracie Challenge." All challengers were welcome to come and fight with the Gracies in no-holds-barred (NHB) matches. The Gracie fighters emerged victorious against fighters of all different backgrounds. The Gracies continued to develop the strategies and techniques they learned from Maeda, honing their skills with the realities of real fighting (Fig. 9.1).

Brazilian jiujitsu, although obviously similar in many respects to judo and other traditional systems of Japanese jiujitsu, differs in some fundamental ways from all other related systems.

The basic Brazilian jiujitsu fighting principles aim the opponent submission. The basic movements usually need to grab the opponent and bring him to the ground. Submission is obtained with several types of upper and lower extremities locks, or by strangulation. This style became very popular at the beginning of mixed martial arts (MMA) championships, on the 1980s, since

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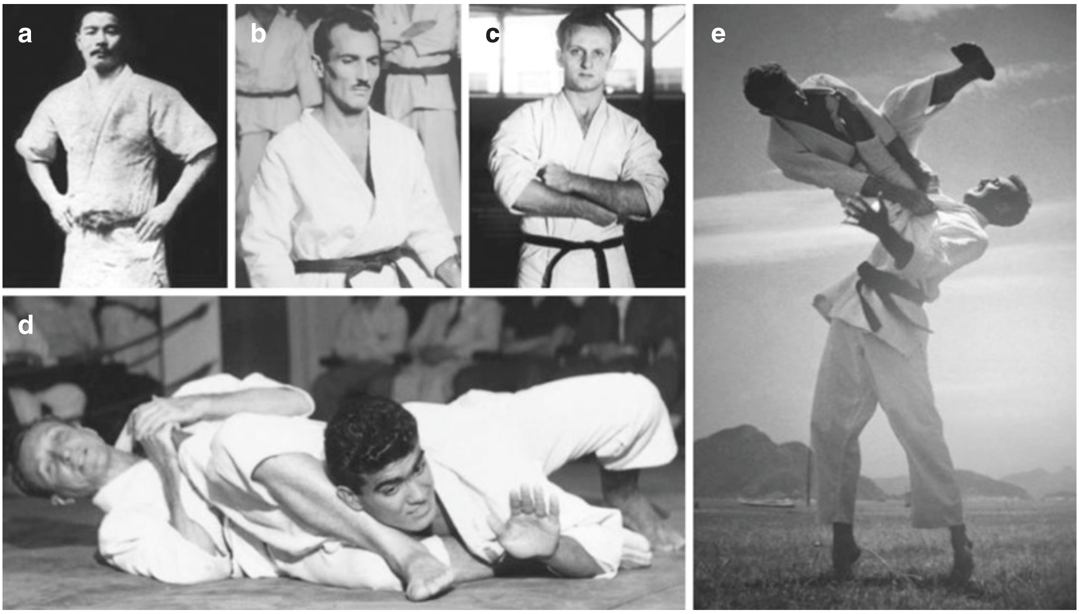

Fig. 9.1 History of Brazilian jiujitsu. (**a**) Mitsuyo Maeda also known as Conde Koma; (**b**) Carlos Gracie; (**c**) Helio Gracie; (**d**, **e**) Carlos and Helio Gracie during fighting and exhibition at Rio de Janeiro, Brazil

Brazilian jiujitsu fighters were able to dominate and win physically superior opponents.

The overall fighting strategy of Brazilian jiujitsu (BJJ) is designed to equip a physically smaller or weaker individual with an effective method of defending against a larger and stronger attacker. When applying BJJ techniques, leverage is paramount, as leverage is the secret to the amplification and the most efficient use of force. BJJ also has the most developed methods of fighting while on one's back, a position weaker fighters will often find themselves when attacked. The innovations of the Gracie family, most notably by grandmasters Carlos and Helio Gracie, and continuing with BJJ fighters today, through constant testing and refinement in the crucible of actual fights, have resulted in this unique style of jiujitsu. Nowadays, this style is popular worldwide and mandatory in the training of the MMA sportsmen. Mastering BJJ is paramount to any high-level MMA athlete who aims relevant achievements on the most important championships of this category of combat (Fig. 9.2).

9.1.2 Hand Injuries on Brazilian Jiujitsu

The hand is not a frequent site of injuries on BJJ fighters, according to literature. The incidence of hand injuries on different studies published about mixed martial arts (MMA) competitions is around 10% (8–13%) of all injuries, being the most common site on the limbs, losing in frequency only for the head and neck injuries (60–70%). That incidence changed a little when only BJJ is analyzed. Head and neck injuries pass to less than 3%, and the most common injuries are on the upper limbs, being the elbow most common site (38%), the knee as the second (19%), and the hand, together with the foot and shoulder, around 11%. A study from 2014 shows the joint injury distribution on a BJJ world championship, and no hand joint injuries were mentioned. That is explained mainly because only the injuries requesting medical assistance were reported, and thus, we can consider the hand injuries that obviously occurred during those fights were basically ignored by the athletes.

Fig. 9.2 (**a**) Two actual Brazilian jiujitsu athletes, collaborators with this chapter: Hernandes Pereira da Silva, World Champion Nogi IBJJF, South American Champion IBJJF, four times Brazilian Champion GI/Nogi CBJJ, and owner of HST Jiu-Jitsu Academy, Sao Paulo, Brazil, and Bruna Marques, World Champion Nogi IBJJF, Brazilian Champion CBJJ, and coach of BJJ in the United Arab Emirates. (**b**) Training situation of armlock

Of course, BJJ fighters, as in other combat sports, commonly have hand injuries, and its frequency may be probably underestimated by the literature numbers. Most of literature data is taken from official competitions and large medical assistance service reports, where supposedly hand injuries with less impairments to the sport are probably not mentioned and not included. Since the direct impact is not the more often mechanism for the BJJ practice, the strains and torsional stress on the bone and joints are the real danger.

The injuries can happen by purpose, during the wrist- and armlocks, and frequently accidentally during the combat, grabbing opponent's kimono or falling to the ground.

Since the torsional mechanism is the rule, we expect to find many ligament tears, chondral injuries, and tendon ruptures in a BJJ fighter's hands.

One important factor, common in most combat sportsmen, but especially perceptive on Brazilian jiujitsu fighters, is a peculiar psychological profile reflected in extreme endurance, pain control, and willpower. These aspects make a typical BJJ fighter underestimate minor (even major) orthopedic injuries during a fight or training. That is made clear by the published data on the before-mentioned study.

Neglected injuries on the hands are a major cause of degenerative injuries on the finger joints. An injury is basically not treated, since the fighter considers himself able to fight. I had a report from a patient who was able to finish (and win) a combat, after a total elbow dislocation! It means the common daily injuries on the fingers are almost never treated properly.

On this chapter, we will stress first the most common mechanism of injuries on the hands of BJJ fighters. Then, we will describe the common lesions leading to degenerative changes on the finger joints. Finally, we will describe the usual treatment options used, adapted to the very special profile of those patients.

9.2 Mechanism of Injury on Fingers

9.2.1 Accidental Injuries

9.2.1.1 Torsional Trauma by Kimono Arrest

This accidental injury is told by the jiujitsu fighter to be the most common and frequent, on daily training activities. Most of jiujitsu maneuvers start in a strong fist grabbing on opponent's kimono. Sudden and wide movements of the opponent may roll the fingertips on its kimono and apply a strong torsional force on the fighter's fingers.

This mechanism can lead to severe fractures or dislocations, but often it only causes mild sprains on the digit joints, or small bone avulsion fractures, immediately neglected by the fighter (Fig. 9.3).

9.2.1.2 Falling and Rolling

The second most frequent type of injury on the hands is consequent to a fall on the tatami, with the hand and fingers on bad positioning. The same mechanism can also happen when the opponent falls over the fighter's hand. This mechanism involves a higher trauma energy and is more frequently associated to major ligament injuries, joint dislocations, or fractures (Fig. 9.4).

9.2.1.3 Direct Impact or Punching

As mentioned before, the normal jiujitsu combat does not allow punches and kicks; therefore, it is not a common mechanism. However, it is a strong combat sports, and this kind of impact can occur eventually, by accident or purpose. Different from typical punching/kicking combat sports, on the jiujitsu, we do not find special protection for hand (fighting gloves), so this kind of trauma when present can lead to severe open injuries. A concerning complication, that is described on this chapter as cause of degenerative changes on finger joints, is the septic arthritis, when the trauma occurs with the opponent's mouth and teeth (Fig. 9.5).

Fig. 9.3 (**a**) Kimono common grasp preparing a strike. (**b**) Maneuver to avoid opponent grasp pulling his arm by the kimono, provoking forced flexion of his wrist. (**c**) Detail of the kimono grasp that leads common finger torsions when opponent makes unexpected and violent body movement. (**d**) Sudden release of kimono grasping as another common mechanism of tendon avulsions and ligament tears

Fig. 9.4 (**a**) Falling over the extended wrist can cause wrist injuries but also finger problems when the hand is not outstretched and some finger may be flexed or rotated. (**b**) Opponent rolling over with his body and hips over the wrist and hand can be another mechanism of injury

Fig. 9.5 (**a**) Punching hard bone prominences can cause fractures on the phalanxes and metacarpal bones. (**b**) Punching opponent's mouth can lead to open injuries with high risk of contamination and infection

9.2.2 Intentional Injuries

9.2.2.1 Armlocks, Wristlocks

One of common techniques is using the leverage force to stress wrist and fingers joints and force the opponent to move on undesired position or into submission. The injury often happens when the opponent holds his position or refuses to surrender, and a joint dislocation or ligament tear can happen (Fig. 9.6).

9.2.2.2 Exiting Guard Positions and Self-Defense Techniques

The guard positions are defense postures where the fighter keeps himself on a safe situation immobilizing the opponent. Several techniques aiming to free one from this guard position, or escaping an offender's attack, force the opponent's body weight against his own hand and wrist, leading to injuries (Fig. 9.7 and Table 9.1).

Fig. 9.6 (**a**) Flexed wristlock, (**b**) flexed elbow armlock, (**c**) extended elbow armlock

Fig. 9.7 (**a**–**f**) Sequence of self-defense maneuvers applying a wristlock on the attacker

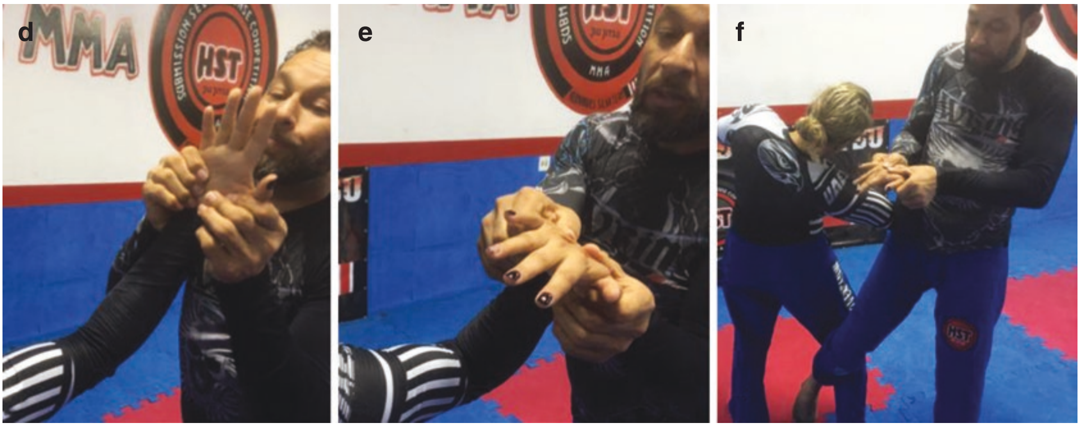

Fig. 9.7 (continued)

Table 9.1 The common acute hand injuries on a Brazilian jiujitsu fighter

1. Fractures
1A. Small avulsion fractures on PIP joint
1A1. Volar plate avulsion
1A2. Central extensor tendon band avulsion
1A3. Collateral ligament avulsions
1B. Avulsions on DIP joint
1B1. Bone mallet finger
1B2. Jersey finger
1C. Torsional fractures of P2 and P1
2. Ligament injuries
2A. PIP collateral ligament sprain
2B. PIP dislocation
3. Tendon ruptures
3A. Swan neck deformity
3B. Mallet finger
4. Open injuries and infection

9.3 Degenerative Changes on BJJ Fighter's Fingers

All the prior conditions described, usually neglected on a Brazilian jiujitsu fighter, may lead to joint degenerative changes. An experienced jiujitsu fighter usually collects a large combination of all those injuries during his sports life. The result is called "Brazilian jiujitsu hand," a general degenerative compromise of all fingers PIP and DIP joints (Fig. 9.8).

The clinical aspect reminds a rheumatic compromise, but the patient is totally different. As mentioned before, the MP joint is usually preserved on the most common mechanisms of trauma.

The clinical presentation is a considerable lack of range of motion and limiting pain. The patient usually will search for treatment when the pain or joint stiffness starts to impair the results on his sport activities, what means a severe compromise of the joint.

Therefore, rarely we will find place for reconstructive procedures, and salvage surgeries are a rule on those patients.

Because of the psychological profile, we must not expect a high degree of adhesion to treatment. The patient will try to come back to fight as soon he feels he is able to. So decision-making on what kind of procedure and surgical technique must take that crucial point in account.

9.4 Treatment Options

9.4.1 Conservative Treatment

By far, that is the most advisable choice on BJJ fighters. Any conservative solution you can find to make the patient able to fight again is welcome. Remind the objective on conservative treatment is coming back to fighting activity.

Fig. 9.8 "Brazilian jiujitsu hands," general compromise of PIP and DIP joints, with a combination of different injuries, including ligament tears, fractures, tendon injuries with mallet fingers deformities, and degenerative global compromise of all fingers. This dramatic presentation is mostly expected on BJJ masters and experienced athletes with long career in official competitions

This is a key point. Most patients are more interested on coming back to fighting than with daily life activities (DLA).

Some options like removable splints, injections, and tapping can restore patient's DLA, but if not restore the practice of his sport, probably he will not adhere to treatment. The opposite is also true, if a solution can allow him to fight, but not to cook, or to drive a car, he probably will be satisfied.

That makes the surgical decision very particular on those patients and often not comparable to other groups.

9.4.2 Surgical Treatment

9.4.2.1 DIP Joint

DIP Fusion

That is by far the best option for this joint. Even in preserved joint surfaces but facing other complex injuries like a chronic mallet finger, joint fusion is more reliable in these patients than other reconstruction technique.

The most popular technique in general for DIP fusion is the use of cannulated headless screws intramedullary.

I recommend this technique for those patients, with the condition of using the stronger screw possible. There are some screws in the market of 2.0 or 2.2 mm diameter and are good options for regular patients, fitting easier the intramedullary canal. But I recommend a 2.5 mm or eventually a 3.0 mm since the size of the bone allows that. Choose a system that permits you to drill the intramedullary canal if necessary, to use a longer and larger screw possible. The distal tip of the screw must stay on the P3 tuff, and the proximal tip must at least pass the istmus of P2 (Fig. 9.9).

9.4.2.2 PIP Joint

PIP Fusion

Instead of being a definitive and reliable procedure, this surgery causes an important lack of function, especially on the fighting, depending on which finger is compromised or how many fingers are affected. It limits the grabbing force considerably if done on the single third or fourth finger. If it is done on a single second and fifth fingers, the compromise is acceptable.

So it is a good choice for the jiujitsu fighter when done in a single index finger or fifth finger. Otherwise, other salvage procedures could be attempted before. The PIP fusion is not a frequent surgery, and when this choice is preferred, the method of fixation must provide a strong, rigid, and reliable stabilization in order to minimize the recovery time and immobilization. Our preferred methods are the intramedullary lag screw or the dorsal-bended plate and screws (Fig. 9.10).

Fig. 9.9 Example of DIP fusion treatment for a chronic extensor tendon injury and a mallet finger deformity. As mentioned before, a more reliable procedure directed to allow an early and successful return to fight is preferable than more complex reconstruction procedures. (**a**) Clinical deformity. (**b**) Exposition of DIP joint, in this case not compromised cartilage. (**c**) Joint cartilage resected. (**d**) Final fluoroscopic control showing our preferred method of fixation for those patients

PIP Interposition Arthroplasty

This is the natural option for the restricted cases described before, as for single fingers treatment on the third and fourth finger or multiple fingers. Several types of interposition techniques are described in the literature. I recommend the use of a tendon graft from PL or other grafts if this one is not available. As alternative local source of graft, you can have a strip of wrist extensor tendons (ERCB or ERCL) or FCR. My preferred technique is to expose the PIP joint volarly, avoiding the disruption of the extensor mechanism. The entire osteofibrous tunnel including the flexor tendons is dissected in a block, subperiosteally and retracted laterally, allowing the PIP to dislocate dorsally exposing all the joint surface. The volar capsule is detached distally, and the arthritic changes must be manually resected,

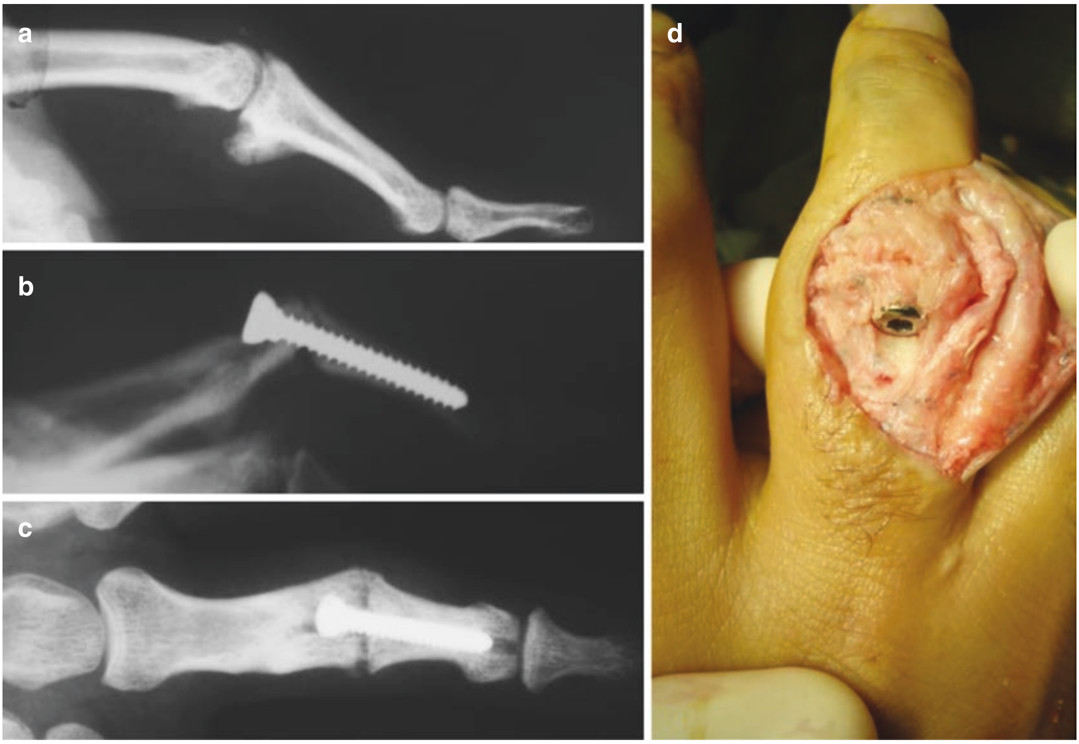

Fig. 9.10 Clinical example for PIP fusion. (**a**) Preop X-ray. (**b**, **c**) Post-op X-ray using the compression intramedullary lag screw technique. (**d**) Intra-op aspect of the fixation during the surgery

providing the original contour of the P1 if possible, using a delicate rongeur. The interposition tendon graft is sutured to ligament and capsule borders wrapping the distal part of P1. The joint is reduced and the osteofibrous tunnel with the flexor tendons restored to midline position and sutured to soft tissues attached to the bone. Stability of PIP joint and full range of motion is tested. Ideally a reasonable stability and mobility is achieved only with soft tissues suture and the maintenance of joint contour. However, in cases where a gross instability is perceived intraoperatively, the use of dynamic external fixators to keep joint alignment allowing flexion and extension with some distraction is a viable option but reminds that treatment needs a good cooperation from the patient.

9.4.2.3 MP Joint

As before mentioned this joint is mostly preserved on usual BJJ fighter. A rare condition for MP degenerative arthritis is after a septic arthritis secondary from an open injury. The case described below illustrates this rare situation.

A 40-year-old BJJ fighter had an open injury on the right index finger MP joint, after a punch on the opponent's tooth. He evolved with severe infection and septic arthritis on the MP joint and submitted to acute surgical cleaning procedure. About 6 months after the trauma, he sustained a painful and stiff joint, impairing him to fight. He had two different proposals for treatment, from general orthopedic surgeons, 1-joint fusion or 2-MP prosthesis, both options recommending him to retire from BJJ competition and practice. We propose him an alternative treatment, aiming the possibility to return to fighting. He was submitted to an arthroscopic procedure for joint cleaning, arthrolysis to regain motion, cartilage resection (partial joint resection arthroplasty), and finally a tendon graft interposition, as shown on Figs. 9.11, 9.12, and 9.13. This salvage procedure gave him a 45° of range of motion and painless joint allowing him to be back to compe-

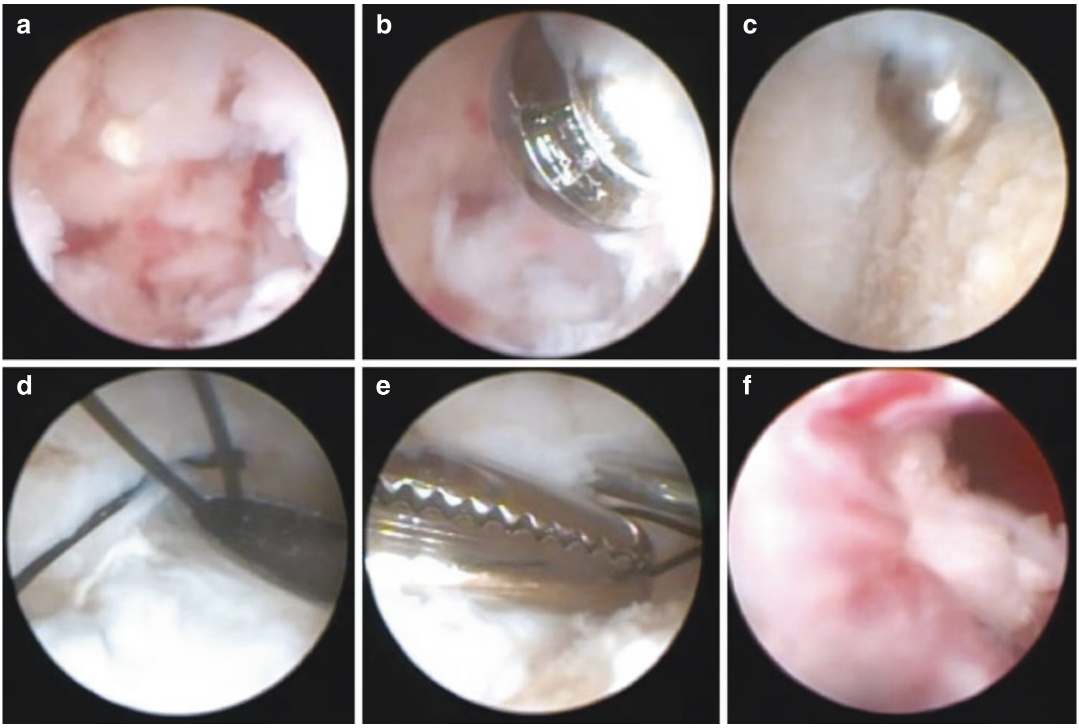

Fig. 9.11 Case described previously. Arthroscopic interposition arthroplasty of the MP joint on a BJJ professional fighter, with painful arthritis and stiffness on the right dominant hand index finger MP joint, after a septic arthritis. (**a**) First aspect of MP joint with synovitis, free bodies, and arthrofibrosis. (**b**) Cleaning of the joint using a 2.0 mm shaver. (**c**) Resection arthroplasty performed, showing the bone surface exposed. (**d**, **e**) Nylon sutures were passed on the four cardinal points of the joint, through the capsule, to anchor the palmaris longus tendon graft interposed on the joint. (**f**) Tendon graft inserted and interposed on the joint

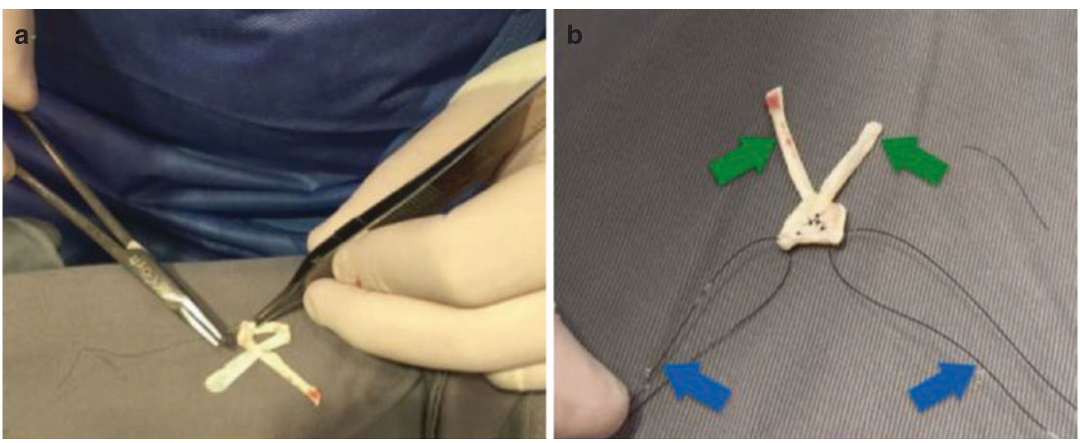

Fig. 9.12 Same case of before. (**a**) Prepare of the palmaris longus tendon graft on a trapezoidal shape; (**b**) detail of the graft prepared, showing the sutures for the anchoring on the joint capsule. Blue arrows, nylon sutures on the volar corners of the graft, and green arrows, redundant tendon graft to be anchored on the dorsal corners of the capsule, on the arthroscopic portals. (**c**) Tendon is inserted by the radial dorsal portal and pulled inside the joint by the previously passed nylon sutures on the volar corners of the capsule; (**d**) Graft is positioned inside the joint and kept wide and open covering all the joint surface by the four cardinal anchoring sutures on the capsule, two volar sutures (blue arrows), and two dorsal sutures on the tendon redundant parts using the arthroscopic portals (green arrows)

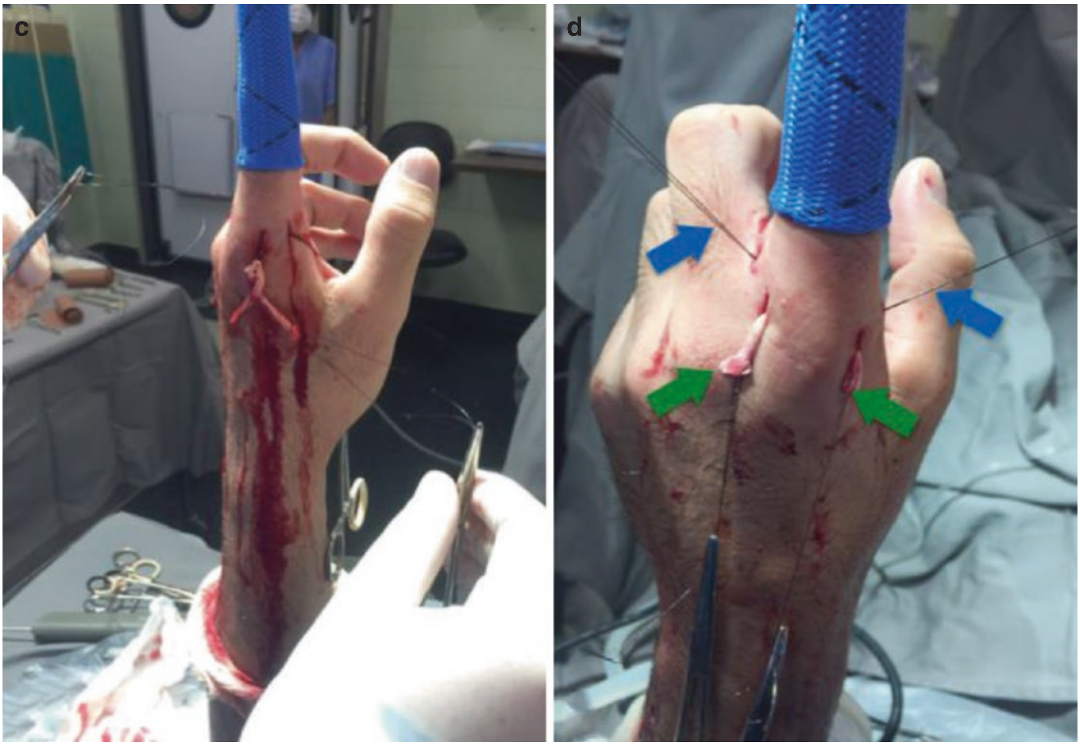

Fig. 9.12 (continued)

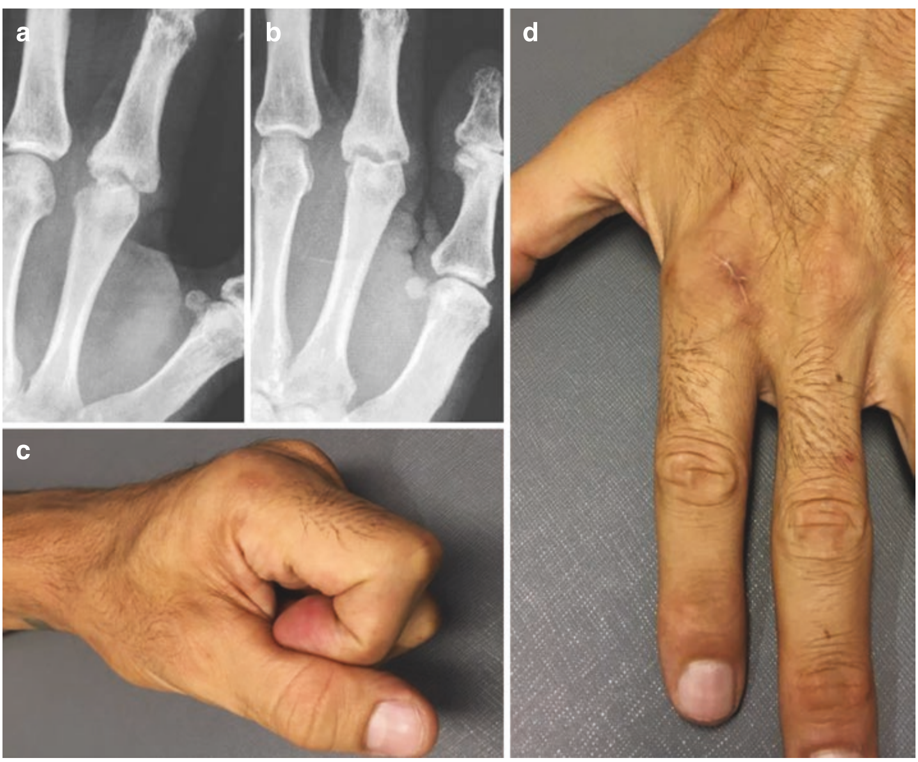

Fig. 9.13 Continuation of the previous case. (**a**) Preop X-ray. (**b**) Post-op 6-month X-ray. (**c**, **d**) Clinical function on 6-month post-op, showing a small but painless range of motion enough to allow the patient to return to BJJ practicing

tition and recreational combat, postponing a more radical and definitive solution (Figs. 9.11, 9.12, and 9.13).

Conclusion

BJJ is a combat sport derived from judo and jiujitsu and is an effective self-defense martial art devoted to practical real-life combat situations facing stronger and heavier opponent.

The special psychological and physical profile of those fighters leads commonly to neglected hand injuries and thus degenerative arthritis on the finger joints.

As the treatment, conservative options are always the first choices and should be able to restore the ability of fighting; otherwise, salvage surgical techniques should be used having this main objective in mind.

Acknowledgments This chapter could not be completed without the collaborations of Hernandes Pereira da Silva (World Champion Nogi IBJJF, South American Champion IBJJF, four times Brazilian Champion GI/Nogi CBJJ, and owner of HST Jiu-Jitsu Academy, Sao Paulo, Brazil) and Bruna Marques (World Champion Nogi IBJJF, Brazilian Champion CBJJ, and coach of BJJ in the United Arab Emirates). I appreciate their gentle support and time, providing pictures and consultancy regarding practical aspects of this sport.

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Hand CMCJ Instability in Combat Sports

10

Amar Malhas and Mike Hayton

10.1 Introduction

Striking blows with the knuckles of a closed fist are common to many combat sports and martial arts, and of these disciplines, boxing is the most studied. Given the nature of boxing, the hands in particular are vulnerable to both acute and chronic repetitive injuries. Tremendous forces can be generated, particularly in the rear hand. Smith et al. recorded just over 2000 N of force generated by a rear hand punch in novices, and this rose to almost 5000 N in elite professionals [1]. The force generated is transmitted across the hand, and the majority of the force is transmitted through the index and middle metacarpals. It has been reported that the index and middle metacarpals transmit 33% of the force while the ring and little metacarpal only 15–20% [2]. As a result, the most commonly affected carpometacarpal joints (CMCJ) affected are those of the index and middle fingers [3, 4].

The incidence of hand and wrist injury is 347 injuries per 1000 h of competition and <0.5 per 1000 h of training. However, as so much time is spent in training, 50–60% of hand and wrist injuries occur during training [5]. Of these injuries, approximately 22% are CMCJ injuries [5] and can cause significant pain and functional limitation in the combat athlete.

10.2 CMCJ Anatomy

There is increasing laxity from the radial- to ulna-sided CMC joints with the index finger CMCJ the most constrained with only 1° of flexion and extension possible, and the middle finger CMCJ is almost as stiff with an excursion of 3°. Subsequently, the degree of movement increases dramatically with the ring and little finger CMCJs, 15° and 40°, respectively [6, 7]. Functionally, this arrangement allows a powerful stable precision grip with the index and middle fingers, while the ring and little finger can flex and conform to provide the power grip. Consequently, the middle and ring fingers are commonly injured in acute trauma [8], while the index and middle fingers are rarely affected [9].

Both the index and middle metacarpals interlock with the carpal bones in a similar manner to dovetail joints in carpentry. The index metacarpal articulation is a sharp concave “V” shape, mainly articulating with the trapezoid with radial and ulna facets articulating with the trapezium and capitate. The middle metacarpal has more of a triangular facet articulating with the capitate [4]. The ring finger has a flatter quadrilateral joint

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articulating with the capitate and hamate, while the little finger has a looser articulation with the hamate alone.

Static stability is conferred by an arrangement of ligaments. The joints are held in place by transverse inter-metacarpal ligaments and longitudinal CMCJ ligaments, which are on both the dorsal and volar surfaces. Interestingly, the transverse inter-metacarpal ligaments are stronger than the CMCJ components, and the dorsal ligaments are stronger than the volar ligaments [10]. The index and middle fingers possess two sets of longitudinal ligaments, while the ring and little possess only one.

Dynamic stability is provided by the insertion sites of the wrist flexors and extensors. The index and middle fingers are braced by the insertion of extensor carpi radialis longus, extensor radialis brevis and flexor carpi radialis. The little finger is supported by flexor carpi ulnaris, through the piso-metacarpal ligament and extensor carpi ulnaris.

The injury mechanism is a cantilever effect much like a seesaw causing repeated axial load and hyperflexion at the CMCJs with the excessive forces causing repeated flexion and opening up of the joint stretching out the intrinsic ligaments and dorsal capsule.

The instability is caused when the contact point occurs volar to the centre of axis of the metacarpal causing a flexion force on the metacarpal head. The metacarpal head is depressed into flexion creating a secondary dorsal levering effect on the proximal end of the metacarpal at the carpometacarpal (CMC) joint (Fig. 10.1).

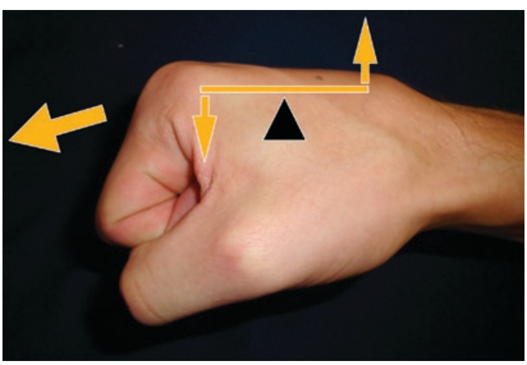

Fig. 10.1 See saw cantilever effect

10.3 Clinical Presentation

Boxers will often present with chronic pain well localised to the CMCJs. They may also report and have a very prominent carpal boss over the back of the hand (Fig. 10.2). They occasionally report the increased laxity in the index and middle CMCJs by explaining their hand buckles upon punching. In very late and chronic cases, over many years additional pain may be caused by degenerative joint changes although in our experience this is very rare. We have seen only a few boxers present with an acute ligament rupture with the avulsion most often distally from the base of the metacarpal (Fig. 10.3).

Often a prefight training camp will exacerbate the symptoms causing them to seek help. Often

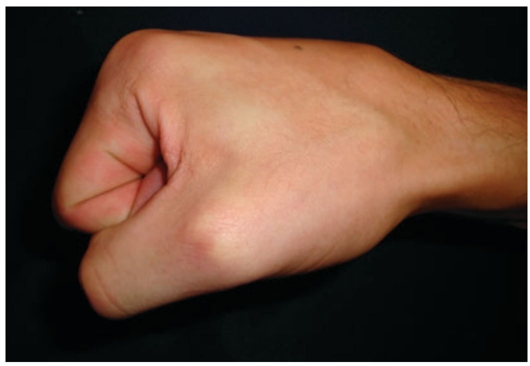

Fig. 10.2 Dorsal thermoplastic splint

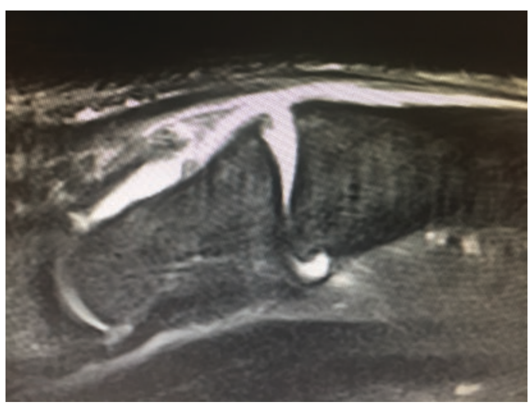

Fig. 10.3 Absent CMCJ ligaments

referred to as having "weak" hands, they report persisting pain, reduced punching power and stamina and often are left unable to compete. CMCJ instability has been historically a potentially career ending condition.

Careful clinical examination will demonstrate CMCJ instability, and this examination technique does require experience as we have encountered many initial assessments by hand surgeons as reporting no abnormality on examination.

Our technique is best appreciated watching a video but basically involves depressing the metacarpal head into flexion, while observing abnormal "opening" up of the dorsal CMCJ. This can be amplified with the examiner placing a thumb in the volar CMCJ area increasing the "seesaw" effect.

Plain radiographs are often unhelpful as they are taken of the open, relaxed hand and miss the dynamic deformation. Occasionally the lateral radiograph will show carpal bossing. In our experience, stress views with dynamic ultrasound or live fluoroscopy will highlight the diagnosis (Fig. 10.4). A flexing force is applied to the metacarpal heads and can often demonstrate widening and subluxation of the CMCJ. Rarely, in chronic cases, a CT scan will be performed to recognise subtle subluxation as well as degenerative changes. CT can show ossification of the volar metacarpal base that may prevent joint reduction and more likely lead to salvage surgery discussed below.

10.4 Management

Given that CMCJ injuries are one of the more common types of hand injury, prevention is an important consideration [5]. The use of gloves and hand wrapping does reduce the rate of hand injuries as the introduction of wraps and gloves to MMA in recent years will demonstrate [11]. Biomechanical testing has demonstrated that the hand wraps themselves can reduce the force transmitted through the hand [12]. Hand wraps appear to support and constrain the more mobile joints (such as the wrist and carpus) and therefore reduce flexion and extension injuries. Despite this, CMCJ injuries do occur during heavy training periods in the run-up to a fight.

Nonoperative measures rely on correct hand care for the striking athlete. Considerations for hand care must include correct wrapping, taping, adjusting training regimes, avoiding excessive punching and custom-made gloves/casts [3]. In our experience, a custom dorsal thermoplastic splint used in training can facilitate a successful training regime while protecting the hand from worsening symptoms in the run-up to a fight (Fig. 10.5). Image-guided steroid injections can be used as a temporising measure but are usually unsuccessful in the long term once carpal bossing and, in rare cases, degenerative joint changes have occurred [4].

Surgery can be considered when the athlete is no longer able to successfully compete, and symptoms have failed to settle with conservative

Fig. 10.4 Fixation CMCJ

Fig. 10.5 Custom made thermoplastic splint

Fig. 10.6 Successful index and middle CMCJ fusion

measures. Soft tissue stabilisation procedures (with temporary K-wire fixation) have been attempted but the long-term results of which are poor [3]. Currently, greater success has been found with selective CMCJ fusion in terms of resolution of pain and return high-level competition [3, 4] (Fig. 10.6).

10.5 Senior Author's Preferred Method: Index and Middle CMCJ Arthrodesis with Autologous Bone Graft

In an appropriately anaesthetised and prepared patient, a dorsal approach is performed taking care to mobilise and protect the finger extensor tendons whilst reflecting as much ECRB and L is required to expose the CMCJs involved. The CMCJ joints are identified, and in some cases, the dorsal ligament and capsule are absent due to chronic instability with the joint open and visible having retracted the extensor tendons. If however the capsule and ligaments are present but lax, they are incised and the joints opened. The articular surfaces are excised sequentially using a sharp osteotome with great care being taken to debride down to the volar surface and ensure the calcified volar metacarpal base is debrided to allow a satisfactory reduction of the joint The articulation between the index and middle metacarpal bases should also be excised to allow inter-metacarpal fusion. The CMCJ must be able to be reduced into full extension, as fusion with the CMCJ in flexion would lead to a weak punch. The exposed cancellous surfaces are then further peppered with several K-wire holes increasing the surface area of exposed bone.

Cancellous autograft bone graft is then harvested from either the distal radius or the iliac crest and is impacted into the defect. The decision for distal radius or iliac crest is largely dependent upon the amount of graft that is required and in our experience; we prefer the iliac crest to ensure adequate volume.

Of particular note is that the iliac crest selected should preferably be from the trailing hip. Therefore, in an orthodox boxing stance, with the left hand (and hip) forward, bone graft is harvested from the trailing right hip. In such situations the donor site is further from the opponent in the unlikely event of there being a painful donor site. More recently the senior author has supplemented the autograft with bone substitute that is now freely available as a paste or granules.

Fixation can then be achieved using a variety of implants including K-wires, memory stables or headless compression screws, and selection would depend upon the surgeon's preference [4]. K-wires may be removed at 6 weeks, while other devices may be left in situ indefinitely. Of note, some boxers may be concerned with the possibility of a future periprosthetic fracture and may ask for staples or screws to be removed.

Postoperatively, the hand is splinted or placed in a plaster cast until bony union is achieved (typically 6–8 weeks). Hand therapy and sports physiotherapy input is then required to regain range of motion and strength. Boxers may return to light punching with hand wraps and padded gloves from 3 months onwards, and force may be increased as the athlete's confidence grows. Full recovery and return to premorbid punching power may take up to 12 months, but in our experience, most boxers return to full punching between 4 and 6 months.

10.6 Operative Outcomes

Nazarian et al., along with the senior author, reported a large series of professional boxers. Their series reported on the results of CMCJ instability surgery in 13 professional boxers. All had failed the nonoperative treatment, and their symptoms were affecting their performance. Initially, four patients were treated with open reduction of the CMCJs and temporary K-wire fixation. Two of these patients failed to settle and went on to an arthrodesis. Further nine patients underwent primary arthrodesis with successful results. One of the nine required a further procedure to graft the proximal inter-metacarpal joint between the index and middle finger. One of the nine patients went on to have their screws removed for fear of further fracture. Full recovery varied between 3 and 12 months, and all 13 boxers returned to competitive boxing. The senior author, MJH, has now more than 40 cases of CMCJ fusions in elite boxers, and all have returning to preinjury level of ability. Furthermore, the senior author has now abandoned ligament reconstruction, even in the little CMCJ, as result of fusions gives a durable and consistent level of satisfaction.

10.7 Summary

Good hand care and protection is a mandatory consideration as part of the treatment regimen of a professional boxer. Prevention is the most preferable option. Development of CMCJ instability requires early recognition and instigation of nonoperative treatment, including dorsal splints. In the event of ongoing symptoms and failure of nonoperative treatment, we advocate primary fusion of the affected CMCJs, over soft tissue reconstruction as a reliable treatment to return athletes to a competitive level.

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11 Use of Arthroscopy for Metacarpophalangeal Joint Injury in Combat Sports

Alejandro Badia

Injury to the metacarpophalangeal joints (MCP) and surrounding soft tissues is prevalent in a variety of combat sports where the closed fist is used to strike, with trauma usually sustained via an axial impaction mechanism [1]. Conversely, sports which involve frequent grappling can lead to injury through a twisting or shearing mechanism to the MCP joint. Surprisingly little has been written on the subject, with most articles emphasizing injury to dorsal capsule (boxer's knuckle) [2]. Regardless of the mechanism, the fighting athlete uses hands and/or feet to deliver a blow or defend themselves, and one must be full acquainted with the type of injuries, however occult, that might be sustained and can limit or even end their competitive career. The arthroscope can help identify these injuries, however minor when intra-articular, and also offer definitive treatment in one minimally invasive procedure.

Small joint arthroscopy has been available, although not commonly used, as early as the 1970s, and although did not become accepted until the late 1990s. Much like the typical knee or shoulder procedure, it has allowed the arthroscope to identify and treat similar pathology but in a small joint environment. Nonetheless, the use of arthroscopy in the smaller joints that remains nearly anecdotal is still virtually unheard of among general orthopedic surgeons, despite not being a new technique. That may be due to scant scientific literature regarding the technique, limited training opportunities/venues, as well as poor understanding of indications and outcomes.

In 1979, Dr. Young Chang Chen first described the concept of small joint arthroscopy, presenting a broad paper on "arthroscopy of the wrist and finger joints" in a symposium on the arthroscopy issue of the Orthopedic Clinics of North America [3]. He described both cadaver arthroscopic anatomy in addition to presenting actual clinical cases involving the wrist, metacarpophalangeal joint, and proximal interphalangeal joints of the hand. In his article, Dr. Chang described the use of a #24 Watanabe Arthroscope, ancestor to today's small joint arthroscope. The first clinical case report of metacarpophalangeal joint arthroscopy came in 1985, where Dr. Vaupel and Dr. James Andrews, sports medicine surgeons, described a thumb metacarpophalangeal arthroscopy in a professional golfer for a 1 year history of pain, swelling, and stiffness in his nondominant thumb [4]. Ryu et al. was the first to describe specific treatment to a collateral ligament injury of the thumb via arthroscopic means [5].

The simple concept that open management of small joint pathology can actually be detrimental to the MCPs; possibly destabilizing the joint or causing excessive stiffness does make arthroscopy

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an ideal technique for treating these common clinical issues in the combat sport athlete. Consequently, arthroscopic management of traumatic joint injuries of the MCP joint in fighting athletes represents a logical option and needs to be better understood by the clinicians treating these individuals.

Before discussing injuries common to combat sports and subsequent arthroscopic management, it is critical to understand the technical aspects of performing small joint arthroscopy.

11.1 Metacarpophalangeal Joint Arthroscopy: Technique

A 1.9 or similar size arthroscope is critical to explore the MCP joint. This is usually a 30° arthroscope and careful attention to minimizing scope damage is prudent. A 2.0 mm mini-shaver, typically a cutter or full radius shaver, is the "workhorse" operative instrument. Small radiofrequency probes (2–2.5 mm), both for ablation and shrinkage, are frequently used. A small joint grabber, as well as small basket forceps, is also needed for more aggressive debridement and loose body removal. A small hook probe is useful as are small Kirschner wires, as these are often used in acute trauma indications. Technical points regarding MCP arthroscopy have only been discussed in a very limited number of peer-reviewed articles [6–8].

All of these procedures are typically performed on an outpatient basis under regional block or even field block/portal local anesthesia using a fast-acting local anesthetic. In our experience it is most convenient to utilize local anesthesia combined with light sedation to minimize patient discomfort from the tourniquet use. The patient is placed in supine position with the arm abducted and the elbow flexed to 90 degree holding the upper arm down with a strap or tape, then suspending the hand using a single Chinese finger trap on the affected digit with 2.5–4.5 kg of traction. A gauze strip is usually tied around the finger trap/skin junction to improve traction as slippage occasionally occurs. The author prefers a shoulder holder so that 360° access is available for fluoroscopy to come in and visualize pinning although a standard wrist traction tower can also be used. The monitor should be placed in front of the surgeon since even minimal motion by the arthroscopist can lead to loss of visibility or prematurely exiting the joint. Adequate sedation is then achieved in order to minimize patient motion and permit prolonged elevation of the tourniquet if necessary. The surgeon must be comfortably seated facing the joint with shoulders above joint level in order to minimize arm fatigue resulting in excessive motion. This requires an adjustable stool and a good assistant to frequently support the scope, while instruments are switched in order to minimize joint exit of the scope. The latter can also be minimized by holding the arthroscope in the surgeon's first webspace, maintaining the index finger on the patient's hand dorsum in order to provide feedback and control depth of arthroscope/instrument penetration. Practice of the technique with a cadaver is crucial to ensure comfortable handling of the arthroscope and handling of the instruments, thereby minimizing iatrogenic damage to the joint surface.

The portals are straightforward, as compared to wrist, with the dorsal joint line located by palpation, with the MCP joint line signaled by two depressions alongside the central extensor tendon under traction (vacuum sign). A syringe with 25-gauge needle containing 2–3 ccs of lidocaine is then introduced into the joint and around the capsule depending on whether regional block is in place (Fig. 11.1). The joint is insufflated with lidocaine mixture and/or saline to distend with an 18-gauge needle and also to determine the scope trajectory angle. Two longitudinal dorsal portals, 2–3 mm in length, are developed on both sides of the central extensor tendon on the digits and the extensor pollicis longus for the thumb. A 15 or 11 blade is used to open the skin and sagittal shroud fibers. Care should be taken not to injure the central extensor tendons or dorsal sensory nerves. Even with distraction, the space between metacarpal head and proximal phalanx base is very narrow, and it is recommended to find the appropriate level and insertion angle. It is particularly important to introduce the blunt trocar or a mosquito clamp into the joint in atraumatic fashion,

Fig. 11.1 Inject index MCP for scope

given that, it is possible to cause considerable iatrogenic injury to the articular cartilage if care is not taken.

Once the joint is insufflated and the joint trajectory is determined, the arthroscopic cannula is then introduced at this same angle, and a thorough joint inspection is performed. The portals are quite simple as they lie on either side of the usually palpable extensor tendon, and the surgeon should feel the indentation just underneath the proximal phalanx base. Occasionally a third portal might be used for outflow and is placed by palpating the capsule, identifying the interval as seen on the monitor, and then passing an 18-gauge needle using standard triangulation techniques.

The arthroscope is placed initially into the most comfortable portal for the operating surgeon, often determined by hand dominance. Then irrigation is established, with a continuous saline infusion using 3 L of normal saline bag under gravity, usually using a pressure bag. Outflow can be with a separate 18-gauge needle although usually established when the 2.0 mm shaver is placed on the opposite portal. We start the joint exam following an organized method that will allow us to rule out pathological changes in sequential fashion.

Joint evaluation is typically done in a systemic fashion to avoid missing pathology. The contralateral side from the arthroscope is usually evaluated first. This includes that side of the metacarpal head and then the base of the middle phalanx. Between them runs the collateral ligament proper and accessory ligament, running a bit volar to the main ligament, which has an oblique orientation, running from dorsoproximal to volar distal. The undersurface of the extensor/dorsal capsule complex is seen dorsally, while the volar plate deep surface can be seen on palmar side. Between the volar plate and accessory collateral ligament is occasionally seen the sesamoid bone when present.

Capsule and ligamentous injury can be easily discerned here, however subtle, once the surgeon is familiar with the normal anatomy and appearance of these structures. Acute injuries demonstrate hemorrhagic changes with tissue fraying and often focal collections of hematoma, interspersed with acute synovitis. More chronic changes demonstrate laxity of the ligaments with irregularity compared to the normal side as well as redundancy of the capsule and more chronic-appearing synovitis.

Once a cursory, but thorough, evaluation of the joint is completed, we proceed with synovectomy which must always be initially performed to allow more in-depth joint assessment and then identification of pathology followed by definitive treatment. This synovectomy is typically done with the 2.0-mm-full radius shaver allowing the capsule and ligamentous structures to become more apparent (Fig. 11.2). Although effective in providing symptomatic relief, it may not alter the injury process in cases of discrete anatomic injury.

A radio-frequency ablator probe can expedite the synovectomy but must be done sparingly, as the joint capsule is relatively thin and subcutaneous and thermal injury can occur to the capsule, articular cartilage, and even the skin (Fig. 11.3).

Once synovectomy is performed, the surgeon can now identify any abnormal findings in a

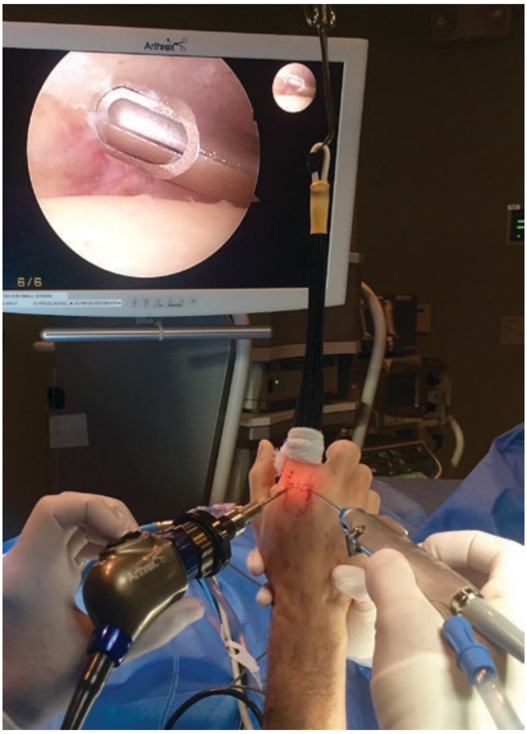

Fig. 11.2 Index MCP shaver debride setup

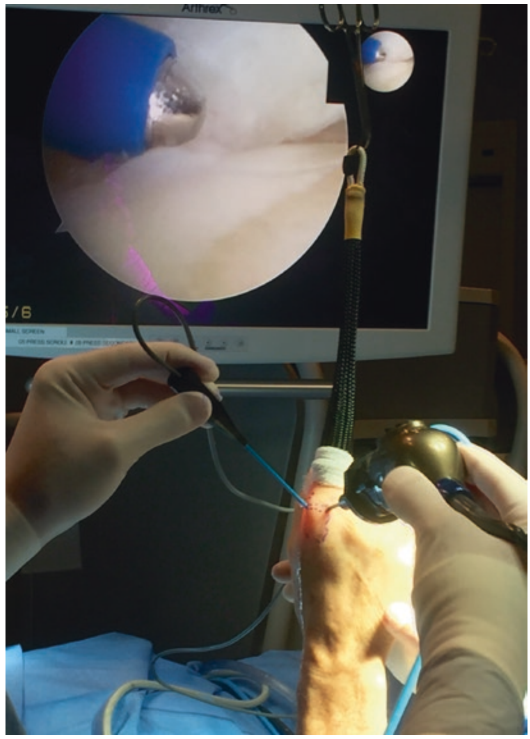

Fig. 11.3 MCP index shrinkage

methodical fashion in order to avoid missing a lesion. The articular surface of both the metacarpal head and proximal phalangeal base is examined from radial to ulnar, from the dorsal capsule to the volar plate. The metacarpal head is wider at the volar end. We should also assess the lateral recesses where the collateral ligaments originate.

The surfaces are examined for integrity of the cartilage and for the presence of any chondral or osteochondral changes. Occult fractures can be seen, but preoperative imaging will usually forewarn the lesion. Arthroscopy will now determine the true degree of displacement. The collateral ligaments are easily visible with its fibers originating in the metacarpal head and running obliquely to the base of the proximal phalanx. Volar to the collateral ligament lies an amorphous fibrous layer leading to the volar plate, a structure we should evaluate next, along with the sesamoid bones.

The dorsal capsule begins at a well-defined dorsal boundary of the main collateral ligaments; with its fibers running longitudinally, we should check its integrity along with the extensor mechanism. There is a recess proximal to the dorsal capsule fibers, filled with areolar and synovial tissue, easily entered and explored in full digital extension. This tissue can become fibrotic and restrict motion, particularly in cases where the MCP joints were incorrectly held in extension for a prolonged period.

On each side of the metacarpal head lies a narrow recess also filled with areolar tissue and synovial folds where the collateral ligaments are born. Fibrosis may also occur here and leads to a chronically thickened joint, often the hallmark of a fighting athlete.

Some anatomic particularities should be mentioned in the MP arthroscopy of the thumb. Here the volar plate is covered by a layer of synovium that, once resected, reveals the articular surface of the sesamoid bones. The radial and ulnar recesses are deeper, wider, and easily accessible when compared to the digits.

Degenerative changes are naturally uncommon among combat sport athletes who tend to be

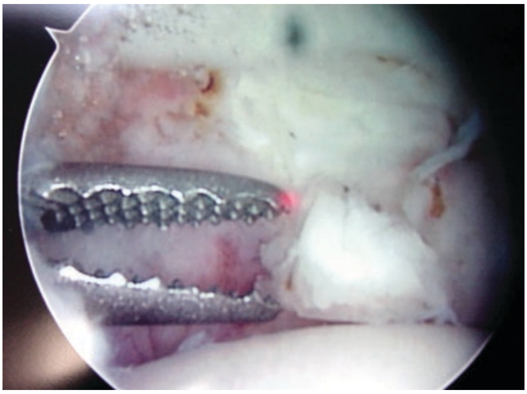

Fig. 11.4 Small joint grabber for excision MCP loose body

younger and in excellent physical condition. Any focal chondral loss in the articular cartilage is treated by mechanical resection of any cartilage fibrillation, loose/unstable fragment excision, and radio-frequency annealment of the lesion edges in order to try and limit further flaking. Full thickness cartilage loss can be managed by drilling the subchondral bone and encouraging the formation of fibrocartilage.

Loose bodies may be encountered lodged in synovial recesses, including the volar plate recess (Fig. 11.4). Examination of the MCP joint is not complete without visualizing or probing into the recesses.

Fractures that have intra-articular extension are easily discerned, whether acute or even healed. Avulsion fractures, typically near the insertion of the collateral ligament on the base of the proximal phalanx, typically have a step-off, and the surgeon can decide whether more anatomic reduction is needed. Fractures near the center of the joint will experience joint-loading forces, whether making a fist, training, or naturally, the axial or glancing force of an impact when striking the bag or an opponent. Less step-off can be tolerated in this region, and arthroscopy remains the ideal modality to demonstrate the true degree of displacement since the articular cartilage is naturally involved as well and cannot be easily imaged. An anatomic reduction of any step-off is more critical in these athletes, since repetitive articular trauma from fighting can cause a mild step-off to progress to degenerative changes that will have profound impact on the fighter.

Naturally, in initial assessment of fighters with MCP joint injuries, it is essential to have AP, oblique, and lateral X-rays of the hand and wrist to assess alignment, congruence, and joint integrity. CT and MRI might better outline the pathology but are seldom needed. Fluoroscopy is extremely helpful in that live fluoroscopic assessment of passive and active joint motion can be determined and periarticular fractures can be visualized in multiple planes. Diagnostic ultrasound is playing an increasing role permitting assessment of the extensor tendon positioning, degree of effusion or joint capsular thickening, and collateral ligament integrity.

Once the pathology is identified and appropriately addressed, the arthroscope is removed, and portals are closed with benzoin or mastisol and Steri-Strips only. Any suturing of portals will lead to scars that will be very apparent on the dorsum of the hand or thumb.

The thumb MCP is protected with a short arm thumb spica splint in extension, and the other digits will usually require a dorsal MCP block splint in flexion. This will allow the collateral ligaments to heal in their most taut elongated position so that there is no resultant extension contracture. An exception is when a sagittal hood rupture is repaired or, for extensor tendon centralization, where flexing the MCP joint can rupture a repair of these superficial structures. The period of immobilization will be largely determined by the type and extent of pathology found during the arthroscopic procedure. Post-op therapy is usually minimal, might begin only days after the procedure, and will focus on maximizing range of motion, followed by strengthening. Edema control is minimal and contractures are rare.

Complications are quite rare in MCP arthroscopy given that there are no motor nerves or critical soft tissue structures surrounding the dorsal aspect of these joints. Radio-frequency thermal injuries can occur if adequate fluid flow is not maintained throughout the use of this modality, and even the skin can be burned if depth of probe penetration is not controlled.

The most common potential complication is iatrogenic articular injury usually caused by surgeon inexperience. Ensuring the correct entry trajectory of the blunt cannula/trocar will serve to minimize this. Equipment damage is actually much more common, and caution needs to be exercised.

11.2 Indications

MCP arthroscopy can be indicated for any of the following pathologies:

- Joint synovectomy and biopsy
- Removal of foreign or loose bodies
- Locked MP Joint (articular causes)
- Capsular debridement and release/capsulectomy
- Osteochondral lesions
- Traumatic (juxta-articular lesions, intra-articular fractures, collateral ligament repair, and debridement)
- Late trauma (arthrolysis, chondral debridement, chondroplasty)
- Rheumatoid synovectomy
- MCP infection I&D

A primary indication for MCP arthroscopy is for chronic pain, which likely suggests degenerative joint disease of these small joints, and acute indications: the management of either acute fractures or ligamentous lesions. It is chronic degenerative indications that are ideally suited for arthroscopic management due to little other options. Only advanced disease, and in low demand patients, could the patient be considered for implant joint arthroplasty. These may be issues that older athletes experience, whether due to underlying arthrosis such as osteoarthritis or secondary to prior trauma which is inherently not uncommon.

Another indication for this procedure is limited function, usually accompanied by pain/swelling that has failed to respond to appropriate nonoperative treatment. Patients who have only a brief beneficial response to corticosteroid infiltration may be the ideal candidates. Even when radiographic changes are not significant, an exploratory arthroscopic procedure may benefit the patient.

While MCP arthroscopy has broader indications than typically considered by the hand surgeon, certain injuries deserve further discussion as regards this minimally invasive technique, particularly in combat sport athletes.

11.2.1 Capsular Injuries

Repetitive impact to the flexed knuckle in fighters will frequently lead to injury: whether an acute, suprathreshold injury, or attritional damage from repetitive blows to the area. Regardless, knuckle pain not responding to conservative measures requires more invasive treatment. Traditional open surgery, such as capsular debridement/synovectomy, is often more destructive than helpful considering that the sagittal hood and capsular complex must be violated in order to then assess for pathology. This is a classic example of how the solution may be worse than the problem. Scarring caused by open surgery should be avoided at all cost in the combat sport participant.

Ongoing pain, often accompanied by low-grade persistent swelling, is an ideal indication for arthroscopic intervention. Simple synovectomy, followed by capsular debridement, typically resolves the issue rather quickly, with athletes returning to training as early as weeks after surgery. Focal fraying of the capsule requires debridement, and subsequent radio-frequency shrinkage will eliminate the redundancy so commonly seen in the capsule including fraying (Fig. 11.5).

11.2.2 Collateral Ligament Injuries

Grappling sports often lead to collateral ligament tears and even complete avulsions due to the twisting of the digits often seen in wrestling, jiu-jitsu, and mixed martial arts. Minor injuries including grade I and II injuries will heal within weeks to months, but more significant tears can lead to chronic pain and even gross instability of

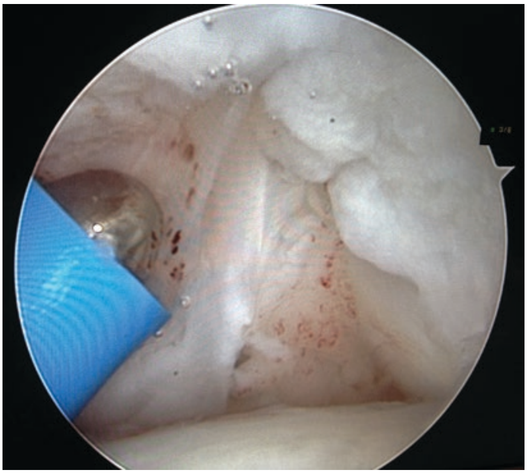

Fig. 11.5 RF shrinkage of attenuated RCL injury

the joint which can render the hand almost useless for any heavy grasping. The patient will present with pain, weakness, and often mild persistent swelling despite months of rest, buddy taping, and even rehab modalities. Corticosteroid injections will temporarily help pain but are not recommended in these types of athletes due to the grip strength needed, and weakening of local tissues from steroid infiltration should be avoided. Granted, this is often done since the alternative would be an open surgery which will not easily recognize subtle ligament injuries and can cause other issues as previously discussed. Arthroscopic debridement addresses the tear directly in a minimally invasive fashion and requires a brief period of immobilization (MCP block cast/splint) for 3–6 weeks depending on severity.

The classic case of collateral ligament injury is on the ulnar side of the thumb (1st UCL) and is often referred to as "skier's thumb," although the traditional term is "gamekeeper's thumb," although the latter actual refers to the more chronic version due to attritional forces. One of the early papers on MCP arthroscopy, by Ryu [5], describes an arthroscopic reduction of the displaced Stener lesion where the ligament is pulled intra-articular with a probe after debridement of the distal insertion site, followed by pinning for 4–6 weeks. However, that should not be considered the prime indication for arthroscopy since a small approach can be used for suture anchor reattachment and ensuring that the ligament is freed up from the adductor aponeurosis. The objective of arthroscopy is not to have small incisions but rather provide solutions for cases where open surgery is neither prudent nor even likely to be successful. A well-defined Stener lesion lends little argument for arthroscopy; however, a "bony gamekeeper" lesion does since the avulsed fracture is usually rotated, is moderately displaced, and can be simply rotated with a hook probe since it usually remains within the joint (Fig. 11.6). Simple pinning then maintains this reduction, while arthroscopy creates an ideal cancellous bed for osseous healing and allows associated synovitis and capsular injury to be addressed (Fig. 11.7a–c). Pin is pulled at 4 weeks when thumb spica cast is removed. This is perhaps the most ideal indication for thumb MCP arthroscopy and can be easily mastered [9]. The lack of scarring leads to rapid recovery and incorporation back into combat sport (Fig. 11.8).

Perhaps more common indication is the chronic UCL and occasional radial collateral ligament (RCL) tear where a previous injury was perhaps overlooked, neglected, or even appropriately treated in a spica cast, but the patient remains symptomatic even 4–6 months after the athletic injury. These are exceedingly common, and arthroscopy now provides definitive solution via late debridement and often thermal shrinkage capsulorrhaphy. Similar thumb spica cast immobilization in needed to allow for healing. The same chronic lesion can occur in the digits, again, after remote twisting injury to the digit where healing does not fully occur. The radial collateral ligament is typically injured in manual laborers and has been a source of frustration for hand surgeons since steroid injections provide only transient relief. However, in the fighting athlete, any digit can be involved since the trauma can be directly sustained by a multitude of mechanisms, most typically determined by which finger an opponent grabbed, twisted, or pulled. Further mechanisms can include catching the finger on one's own Gie, or that of the opponents, and a glancing blow to the opponent causing the injury. Finally, falls to the mat/flooring can also lead to collateral ligament injuries as well.

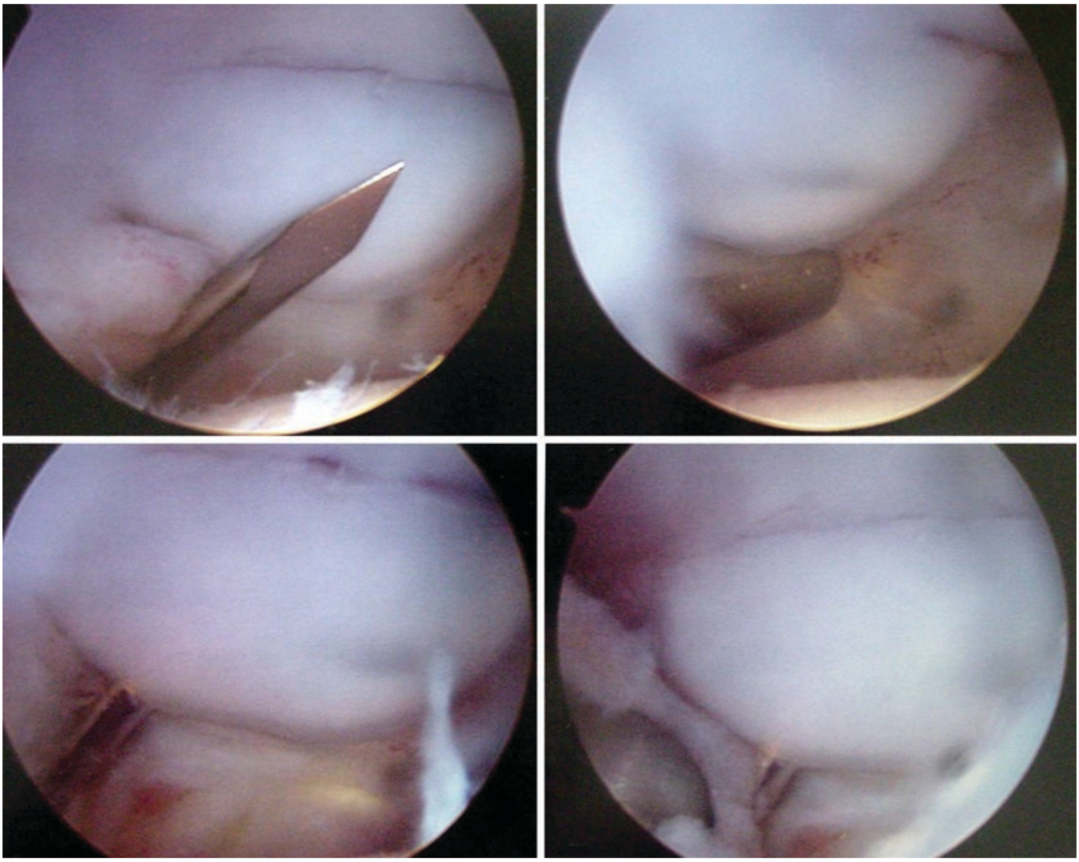

Fig. 11.6 Sequence shows arthroscopic pinning of derotated collateral ligament avulsion fracture

11.2.3 Intra- and Periarticular Fractures of the MCP Joint

Bony avulsion fractures at the collateral ligaments, typically the thumb, have already been discussed and represent more of a type of collateral ligament injury.

The classic diepunch fracture of the proximal phalanx base is ideally suited for arthroscopic treatment, much like the tibial plateau fracture of the knee. Depressed fragments can be elevated, confirmed to be anatomically reduced, and then pinned percutaneously. If a hook probe is not successful, a small distal incision to the joint can be used to tamp the fragment into place via a small cortical window. Standard bone tamps are too large for this indication, and I will typically use a small curette. More significant fractures of the articular surface, whether of the metacarpal head or proximal phalanx, can be reduced with fluoro but fine-tuned via arthroscopic means. Once the reduction is seen via the scope (after synovectomy and fracture site debridement), K-wire pinning is typically used allowing them to be removed 4 weeks later. Compression mini-screws can also be used when the fragments are substantial and to also assist in expediting recovery in the high demand athlete (Fig. 11.9a–d). Fluoroscopy can be brought into the field (usually perpendicular to forearm axis) and confirms reduction but also guides pinning and screw placement. The combination of small joint arthroscopy with further instrumentation (such as pinning/screw insertion) and fluoroscopic control therefore requires significant technologies to be

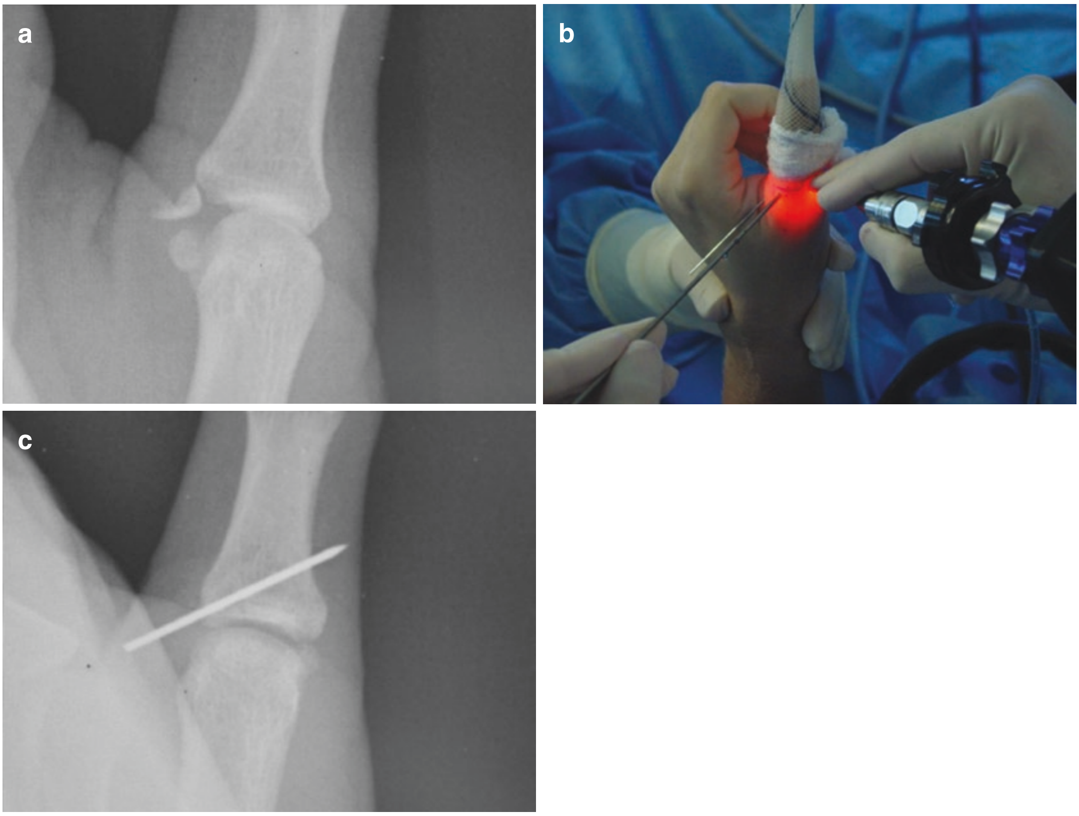

Fig. 11.7 (**a**) Rotated UCL avulsion fracture of thumb in judo athlete. (**b**) External view showing 1.9 scope in radial portal and K-wire in place reducing UCL avulsion fracture. (**c**) Reduced avulsion fracture via ARIF with subcutaneous pin

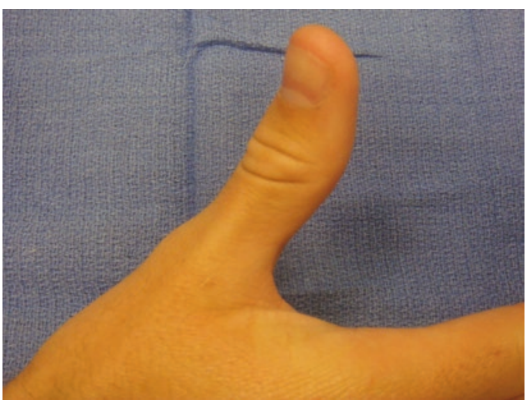

Fig. 11.8 External view of thumb after ARIF bony UCL injury

implemented in order to achieve the desired, optimal result for these high-intensity, fighting athletes. This OR scene has been termed a "Techno-Fest" by hand colleague, Dr. Richard Berger.

On rare occasion, a metacarpal head articular fracture can be combined with a displaced neck or even shaft fracture as well. In this case, I prefer to use a single orthograde intramedullary pin, introduced at the MC base, and then cut under the skin proximally. Traction is then applied (confirming maintenance of reduction), and the arthroscopic component of the surgery is then performed.

Finally, much like in wrist arthroscopy, associated lesions can be identified and treated when

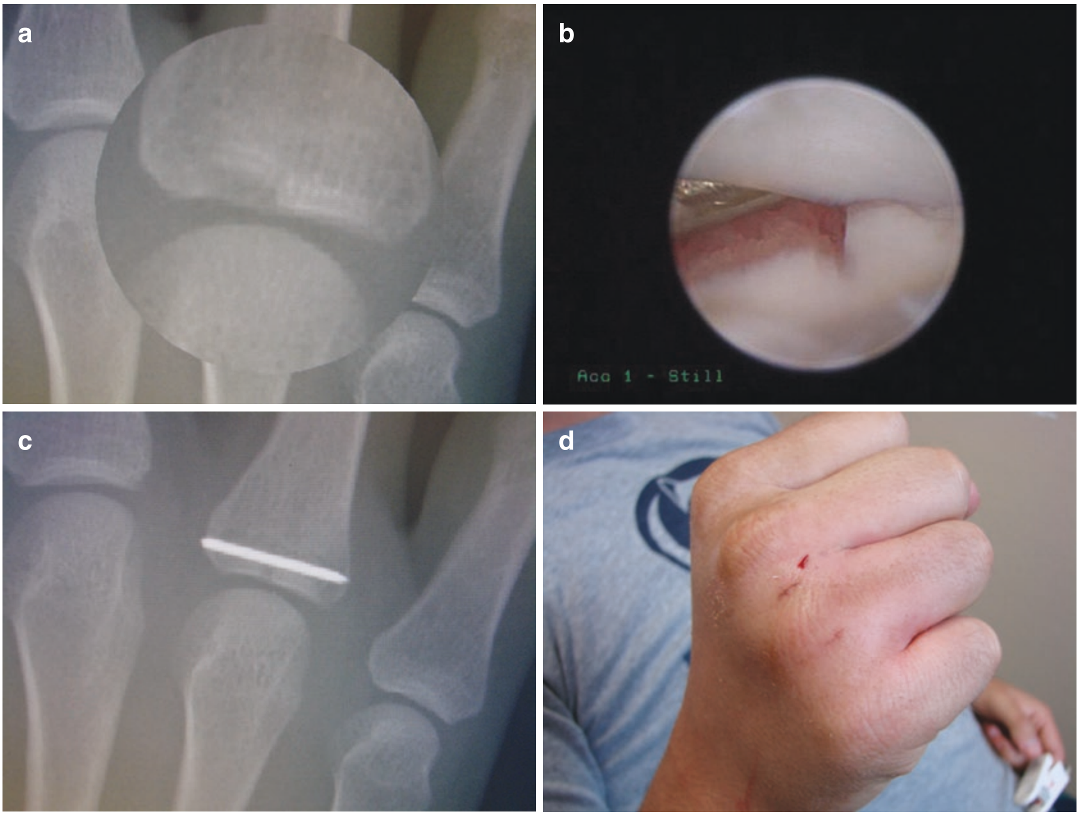

Fig. 11.9 (**a**) Magnified radiograph showing proximal phalanx base diepunch fracture. (**b**) Proximal phalanx base FX being reduced by small JT hook probe. (**c**) Diepunch fracture reduction held by single subchondral k-wire. (**d**) Post-op external image showing portals – no sutures at time of MCP block cast application in fighter

an articular fracture of the MCP joint is addressed via the scope. Technology has given us the means to do it, and these high-intensity sportsmen demand an optimal result which can best be achieved by using all the tools available to us.

Conclusion

Combat sport athletes participate in a variety of fighting sports that can cause impact or twisting injuries that lead to a spectrum of pathology discussed. The minimally invasive nature of metacarpophalangeal arthroscopy allows the surgeon to better recognize occult pathology that interferes with the athlete's performance, and provides a preferable methodology for definitive treatment since it avoids the longer, more painful recovery process seen with any open surgery.

Indications for MCP arthroscopy need to be better understood, and younger surgeons need to be trained at an early stage so that this becomes a natural option within their treatment armamentarium. To that end, modifications to current arthroscopes and instrumentation will lead to optimization and increasing adoption of these novel techniques.

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Hand and Wrist Injuries in Aikido

12

Ugo Montevecchi

12.1 What Is Aikido?

Aikido is a martial art that is distinct from all others for the peaceful spirit with which it is practiced. This characteristic was determined by the will of its founder *Morihei Ueshiba* (1883–1968), one of the many teachers of Japanese martialism to be universally known as *O Sensei*, literally Great Master. The method he elaborated in fact is not just one of many martial styles, but it is a guide to seeking harmony and peace among men. Despite the unquestionable effectiveness of its techniques, Aikido is therefore a path for people who, through a martial "way," have the will to grow and improve. The techniques are only defense, and for this reason there is no concept of comparison in Aikido, nor less a race, impossible to be achieved between two people whose intent is only to defend themselves. There is no study of how the shot is taken to break down the opponent: during *keiko* (training) the jacks and shots are only brought to allow the partner to study the defense technique, and the training takes place in a spirit of full collaboration avoiding as much antagonism as possible and competitiveness among practitioners. Providing his own attack and body to his partner to allow him to study the technique is a gesture of extreme generosity and altruism that normally determines Aikido's dojo in a positive atmosphere of growth through collaboration and mutual help, avoiding any manifestation of violence and exaltation. Through the methodical study and refinement of the techniques, it is therefore aimed to obtain first and foremost an evolution on a physical-athletic plane and, then in the character, with the aim to achieve an evolution even on a spiritual level. In aikido there are no concrete results to be pursued; even grading examinations are not a goal but rather a means to encourage and stimulate growth and steps to be taken to rationalize the path to purely technical follow-up. In Aikido there is no *kata*, the perfect model to replicate: the different character of each and the different physicality are sufficient enough to determine a different evolution in every person. After years of experience, the practitioner, as a true "artist", then elaborates his own personal way of performing the techniques that increasingly become the result of the individual evolutionary path. However, the same person changes over time, grows, grows up, grows old, and finds himself in the need to constantly change his Aikido. There is therefore no tangible and concrete result to aim at; the aim of practice is the practice itself, a constant search for one's personal expression, and subjective perfection, a way that never ends.

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12.2 What Are the Aikido Techniques?

Consistently with the spirit of positivity that distinguishes it, Aikido is practicing trying to avoid any injury to people with whom you train. The techniques that are being studied have always been the final outcome of the projection of the partner (Fig. 12.1) through a displacement or immobilization on the ground. In both cases, levers on joints are applied for the control of the other. The movements of change of position are mostly circular and are able to dodge, coming out of the attack line and then returning to the attacker its own energy. The levers are performed with control and moderation and can have a beneficial effect by stretching the muscles and mobilizing the joints, but if they are applied abruptly, they are potentially devastating, easily causing fractures, severe tendon-ligament injuries, and muscle damage. Normally, during the activity, trauma is rare because the spirit is that of collaboration. Who applies the lever (defined as *torì*) takes full care to avoid causing trauma. Experience plays a fundamental role, and while the practitioner increases his ability, he matures in parallel an increasing sensitivity that allows him to apply the techniques with speed and effectiveness while maintaining control of their dangers. On the part of those who provide the attack (called *uké*), it is essential to have the willingness to accept the technique constantly, reacting to this promptly and relying rather than refusing it with stiffening or illogical movements. The first necessity of the practitioner in the role of *uké* is to master the *Ukemi,* that is, the techniques of falling, to avoid being traumatized when projected to the ground. With the experience you learn then all those movements that, taking advantage of the elasticity and mobility of the entire body, allow those who suffer the technique of not suffering injuries. Training with an experienced practitioner, who knows how to avoid trauma with the right fidelity and the right moves, is the best condition for progressing in the Aikido study. Having this opportunity, the levers can be applied effectively and fully because the expert *ukè*, while maintaining an attacking attitude, knows how to absorb the technique without any consequences. At the time of interpreting the role of *torì* instead, they study the actual techniques. It starts from the learning of basic movements and techniques in their most basic form. It continues by studying how to get rid of the various shapes on the wrists and then switch to more complex

Fig. 12.1 Projection techniques are an expression of balance and plasticity typical of Aikido

gripforms and from the front, lateral, and back blows. Aikido's movements are largely due to the handling of two Japanese traditional weapons, the *Jo* (130-cm-long stick) and the *Bokken* (wooden curved sword that even the ancient samurai used as a training tool replacing the *katana*). The use of these weapons along with the *Tanto* (wood knife) is an integral part of the training, especially by experienced practitioners.

12.3 Causes of Injury in Different Aspects of the Practice

Accidents in Aikido practice can take place in various situations that can be grouped into three main categories that will be examined individually and more analytically.

12.3.1 Practicing Techniques

Splitting practitioners into two categories, we might consider beginners and advanced. Obviously there are no defined limits between the two levels, and the transition from one category to another is determined only by the experience that one matures with practice. It's a fact, however, that beginners and advanced, especially when they train separately, have different ways of practicing, and we may also say that they have different ways of getting physical problems. It can be said that if beginners get hurt more often, seldom they get serious injuries, while advanced ones, by virtue of their greater experience, are hardly injured, but if they occur, they can be of greater magnitude. Why does this happen? The effectiveness of Aikido's techniques is not based on the muscular force used in applying the levers but on the precise execution and on the perfect harmonization of the movements of the defenders with those of the attacker. Unfortunately, very often inexperienced practitioners, looking for an immediate response to the effectiveness of their technique, tend to undergo poor skills with the use of greater muscular strength in control jacks and levers. As if that was not enough, the beginner did not have the clear ideas on how to follow the technique he undergoes. Often he fears it and so can happen that it reacts with a stiffening. In other words, instead of letting go so that the body naturally absorbs the partner's control, it tends to slow down or stop its movement falling victim to a comprehensible contrast to the technique. Each time a lever is applied, there is always a tendon-muscular structure that is subjected to extreme stretching, but it is obvious that if muscle contraction takes place at that moment, tension increases and with it the risk of injury. This is the typical situation that every Aikido master has to face by teaching beginner classes. The occurrence of these dynamics is in any way counterbalanced by the need to route the students to aikido's proper practice without the use of force and to prevent them from having physical problems. The fact that during the practice, there is no will to harm your companion unfortunately is not a sufficient guarantee, and even if seldom, accidents happen! Uncorrect execution of technique, too much fog, excessive speed, and exaggerated force are the possible guilty of those who play the role of *torì*. On the other hand, who plays the role of *ukè* has the responsibility if, instead of staying relaxed, gets stiffened and if, instead of following the movement agile, it stops or moves too slowly. Another common risk situation is to act as *ukè* trying to anticipate the action of the *torì*. If you make a wrong interpretation, it may happen to be moving illogically and inappropriately, in contrast to the movement of the *torì* rather than being well coordinated with it. In summary, we can say that accidents among beginners are mostly determined by the inexperience and the lack of harmony that is just the case with what is practiced and pursued. The lack of tune-up between *ukè* and *torì* is also the cause of injuries among the advanced. These are more seldom wrong, but having more technical skills are used to moving at speeds, applying levers with great determination and energy, so whenever there is a misunderstanding, the consequences are more serious. It is then worth mentioning a classic situation, causing minor injuries, which is determined when the beginner woman trains with an advanced male. It often happens that, in an attempt to encourage the novice in any way, the advanced impart the correct technical suggestions, while at the same time providing the maximum of muscular relaxation in giving themselves how to do it. Well, in this condition it sometimes happens that the beginner is able to carry out the movement properly but that, by excessive zeal and lacking confidence in his muscular strength, apply the maximum energy to the lever, letting the available male partner lose and sore. It is noteworthy that all cases of injury so far reported are independent of the will. But at this point, the question arises spontaneously: what would be the consequences of these techniques if applied with the will to harm and if applied with great speed and energy to a person who has no knowledge of how to absorb and which may react with an instinctive stiffening? In this case I came to the conclusion that osteoarticular structures damage could really be serious. This is confirmed by the fact that the incidence of accidents, in particular the serious ones, was higher in the past. Currently Aikido is well known, and with access to the web, it is very rare that anyone who goes to a dojo of aikido does not already have the clear ideas about the spirit with which this martial art is practiced. Adventurers are now pretty well selected on the basis of mentality and expectations, but in the time of the pioneers, the 1960s and 1970s, things went a bit differently. Those who enrolled in an Aikido Dojo or any japanese martial art made no distinction and claimed shortly to acquire personal defense skills and bare hands combat. The spirit of coaching work was “See if I can hurt you with what I’ve learned”, and the curiosity about the effective efficacy of the technique led to trying to withstand you to test your training companions and sometimes the same masters. The result was a much less refined and sophisticated aikido than what the Japanese Masters now propose; it was a much more essential Aikido, spartan, muscular, sometimes brutal, and therefore inevitably more traumatic.

12.3.2 Performing the Ukemi

Another frequent cause of injury is incorrect execution of *ukemi* when it is projected. Factors such as the low professionalism of the master, the carelessness, and the rush to practice projection techniques can pose some risks. Those who teach should therefore always adopt a didactic approach that focuses on the safety of their students. For beginners, wanting to emulate the advanced, sometimes they are driven to advance the times, and, by transgressing the wise instructions of the master, they experiment with *ukemi* that do not seem to be in their reach yet. In fact, the accidents that occur in performing the techniques of falling are mostly due to the shoulder and neck, but sometimes even fingers and wrists can suffer trauma. Even the advanced in the cunning of the techniques can make mistakes and suffer consequences, but it is clear that with the growth of experience, the accidents due to the incorrect execution of the *ukemi* become an increasingly rare occurrence. There is also the risk inherent in the unprecedented: clashes between athletes who are projected simultaneously on convergent trajectories and bumps with obstacles such as walls or columns, perhaps just to avoid colliding with a companion, are all casualties that constitute a small inevitable risk percentage.

12.3.3 Handling the Weapons

Let us now consider accidents during practice with weapons. Again, the energy and the speed with which the attacks can be taken should take into account the ability of the *shitachi* (who defends in practice with the weapons), which must be able to dodge and parachute the shots of the *uchitachi* (who attacks in practice with weapons). Since exchanges normally involve sequences in which practitioners alternate in the role of those who attack and defend, it is apparent that training with weapons is far enough that partners are of a similar technical level. When two beginners train with weapons, the rhythms are generally very dull. The complexity of the sequences generally makes it difficult for someone who is not expert and forces him to run it slowly. Handling a weapon then causes an instinctive fear of getting hurt each other, helping to reduce the risks. Often, those who teach, in order to stimulate beginners more, offer mixed pairs, and in this case, even if the rhythms become more sustained, the presence of an expert is sufficient to guarantee safety. In practice between advanced, when shots are brought in decisively and quickly, training can become dangerous. Real combat in Aikido is not foreseen, and hence weapon manipulation is always lacking in the will to harm. Nevertheless, in this area of practice, not least in others, accidents occur: tiredness, distractions, or simple misunderstandings can cause wounding through blows mostly affecting the head, face, and hands. If gloves or protections are not expected, if the hands are affected, they are always more or less serious injuries.

12.4 Injuries During the Execution of the Individual Techniques

Let us now analyze the individual situations in which the injuries occur, starting from those that are part of the above mentioned category, that is, the trauma during the execution of the techniques.

The easiest way to do this is to analyze one by one Aikido techniques and see how they act on the anatomy, soliciting the various structures of the locomotor system. Obviously the techniques involve several districts of the body, but given the specificity of this publication, we will only consider traumas that affect hand and wrist.

12.4.1 Ikkyo

Ikkyo is the basic technique of Aikido, and even though the newbie may seem strange, much of the techniques is derived from or has relevance with it. Precisely for this reason, the term Ikkyo could simply be translated with "First Principle of Leverage" or "First Aikido Technique." It is carried out by leveraging the shoulder so as to achieve an overturn and twist of the joint (Fig. 12.2). What you get is a partner's imbalance that ends with its landing. Because the

Fig. 12.2 Spilling of the shoulder by applying the Ikkyo technique

solicitation is restricted to the shoulder joint, if hand and wrist trauma occurs during *Ikkyo's* practice, they never affect the limb but always the contralateral hand and wrist, that is, the ones *ukè* uses to lean while, forced by the lever, dragged to the ground in a pronation position. It can happen, especially in the form of *urà* (in which those who practice the technique absorbs the energy of those who attack by turning to his shoulders) in which *ukè*, falling to the ground with much energy, does not support his hand sufficiently forward to stop the fall in a proper way and that his body, driven by inertia, continues to advance beyond the support producing an hyperextension (lever) of the four fingers. The hyperextension can cause an articular dislocation (subluxation), but it hardly has serious consequences because the four fingers are always involved at the same time and the load, though excessive, is always subdivided all over in a fairly uniform manner. *Ikkyo*'s direct-to-thumb traumas are virtually absent, but by doing this technique at least in one case, the accidental fall of the *torì* with the knee on the hand of the *ukè* caused the unforeseeable fracture of the thumb.

12.4.2 Nikkyo

"According to the principle of leverage." This technique involves the articulation of the shoulder in the same way as the previous technique but associates with the shoulder control a flexion and twist of the wrist that is fully flexed in the palmar and internal rotation. This technique, especially in the *urà* form (Fig. 12.3), if applied with precision and intensity is extremely painful and is one of the most common causes of tendinitis to the hand and to the wrist with frequent onset of pain in the forearm, whose muscles may remain damaged by tear in its palmar portion. There is a variation of *Nikkyo* which, for its very painful application, is studied very rarely, and the masters define it as "police technique" (Fig. 12.4). This technique causes an acute pain in the wrist that is placed in flexion. It is used by the Japanese police to force people to desist from any resistance at the time of arrest. It is achieved by grabbing the attacker's thumb after knocking the shoulder with the *Nikkyo* lever. Once the control condition is reached, the use of one hand may be sufficient to cause a great pain and then induce the person to desist from further resistance attempts.

Fig. 12.3 Lever on the wrist applying the Nikkyo technique

Fig. 12.4 Lever on the wrist by applying a variant of the Nikkyo technique

12.4.3 Sankyo

"Third principle of leverage." *Sankyo* also plans to overturn the shoulder, but in this case the hand, the wrist, and consequently the forearm are forced into a very intriguing intrarotation. Those who undergo the technique find themselves with their elbow facing upward in maximum flexion with the hand at the level of the axilla and the elbow at the level of the head. In this condition, if *ukè* tries to relieve tension from the lever, he will be forced to move on his toes walking backward. The lever is obtained in several ways, starting from the *Jkkyo*-type lever but also in the form *Uchikaiten* (under the arm) and *Sotokaiten* (externally to the arm). To get effective control, you need to grab the hand of the attacker with two hands (Fig. 12.5). The main grip is the one that grabs the *tegatana* (literally "hand sword," the margin of the hand corresponding to the fifth metacarpal), while the accessory hand tightens the fingers so as to obtain, in addition to the intrarotation, a hyperextension of the fingers wrist. Important traumas, or the sum of microtraumas due to excessive stress, often cause tendinitis (e.g., at the wrist: the abductor pollicis longus of the thumb) and epicondylitis at

Fig. 12.5 Wrist and elbow lever by applying the Sankyo lever

the forearm and elbow levels. This technique can also produce injury and tendinitis to the hand and to the fingers and, if carried to the extreme, fractures or muscular tears. *Sankyo*, for its effectiveness, is also used by Japanese police to force people to stand up whenever they sit or lie down on the ground refuse to do so.

12.4.4 Yonkyo

"Fourth Principle of Leverage." This technique consists of a sort of sum between the shoulder lever that is obtained with *Ikkyo* and that of the wrist realized with *Sankyo* (Fig. 12.6). Obtained the control of the *ukè* by the combination of these two levers, to immobilize him on the ground, a strong pressure on a point of pain at the wrist level is applied. This point should be sought as close as possible to the insertion of the flexor carpi radialis tendon that is first tensioned by the wrist extension and subsequently urged by strong pressure. Obviously, the combination of the two causes pain and sometimes numbness of the hand, but very rarely it determines real injuries that leave medium or long-term consequences.

12.4.5 Gokyo

"Fifth principle of leverage." This technique involves the elbow only. Those who realize the technique will use one hand to control the wrist of *ukè* by applying a pressure on the dorsal side, while the other hand will grab the fully elongated elbow with a strong traction (Fig. 12.7). The shoulder will also be leveraged forcing those who receive the technique to go to the ground and find themselves in a prone position. The hand and wrist are not involved in this technique.

12.4.6 Rokkyo (Hijikimeosae)

"Sixth Principle of Leverage" more commonly called *Hijikimeosae* "immobilization with elbow lever." It is achieved by pressing the arm firmly on the back of the joint (elbow) when the limb is fully extended (Fig. 12.8). The elbow lever is in this case combined with the *Nikkyo* lever applies to the wrist. The control with *Hijikimeosae* can in fact be considered a kind of variation of the *Nikkyo* technique performed in a *urà* form (this involves the absorption of the attack by turning

Fig. 12.6 Pressure on a point of pain by applying the Yonkyo technique

Fig. 12.7 Crank and shoulder lever obtained by applying the Gokyo technique

Fig. 12.8 Lever at the elbow applying the Rokkyo/Hijikimeosae technique

the back of the aggressor, as opposed to the *irimì* forms where the aggressor is anticipated by entering in front of him). The *Rokkyo* technique can cause very serious damages to the elbow, while at the wrist and the hand level, it has the same consequences as the *Nikkyo* lever.

12.4.7 Shihonage

"Projection by cutting" (in four directions). Through a circling in opposite direction to that of *Ikkyo*, you get the result to lose the balancing of the attacker, forcing him to buckle his back. *Ukè* comes with its elbow flexed facing upward and with his hand behind his shoulder. In this position, the wrist will be heavily flexed and extra-rotated (Fig. 12.9). Stronger stress is at the level of the elbow that can easily be dislocated. To avoid damages, the technique normally ends up by providing the partner with a push that tends to reduce the elbow from exaggerate tension but strongly bounces backward causing a fall that is usually absorbed by the execution of the *Sensu Ukemi* (falling to fan) or *Ushiro Ukemi* crossed as described in the "Ukemi Manual" (see bibliography). However, if the technique, accidentally or deliberately, is carried out not with the idea of "pushing" but by "pulling out," it can cause damage to the tendon-ligament structures of the back of the hand and the wrist as well as tears of the flexor muscles of the wrist. A very rough execution of this technique causes the floor to fall with direct impact of the head so much that in the past has caused serious consequences and deaths.

12.4.8 Kotegaeshi

Literally "spin your wrist." The condition in which the wrist is located by applying this lever is very similar to that obtained with Shihonage. Even in this case, there is a back unbalanced of the attacker without the buckle of the back. The technique is achieved by holding the jaw pulp firmly with one hand and the other applying a strong pressure with the ears and hypotheses on the dorsal and metacarpal side, thereby placing the hand flexion wrist (with addition in certain variants of an extrinsic component) (Fig. 12.10).

Fig. 12.9 Lever on the wrist and imbalance obtained by applying the Shihonage technique

Even in this case, any damage concerns the tendon-ligamentous structures of the dorsal portion of the hand and wrist.

12.4.9 Iriminage

"Projection to the body (of the attacker)." The projection is achieved by leveraging the neck. Using his arm-shoulder, lift the chin of the attacker by forcing him to buckle his back, and fall for the combination of a side imbalance first and then backward (Fig. 12.11). This technique can be achieved by applying the neck as well as a backward bending also a strong twist. This makes it even more effective but also quite dangerous, causing damage to the cervical spine (in the past there have been several cases of death and tetraplegia!). *Iriminage* does not involve in any way hand and wrist.

12.4.10 Caitennage

"Circular projection." This technique as *Sankyo* can also be realized in *Sotokaiten* and *Uchikaiten*, taking the double denomination of *Sotokaitennage* and *Uchikaitennage*. The lever, which involves the shoulder and elbow, first forces the attacker to bend forward (Fig. 12.12) and then, insisting on the lever, to run a *Mae Ukemi* (rolling forward). Usually there are no consequences for the hand and wrist.

Fig. 12.10 Lever on the wrist applying the Kotegaeshi technique

Fig. 12.11 Imbalance obtained by applying the Iriminage technique

Fig. 12.12 Shoulder lever and imbalance obtained by applying the Caitennage technique

12.4.11 Tenchinage

"Sky-ground projection." The technique provides lateral and backward imbalance (Fig. 12.13). The attacker fits the energy of the unbalancing using various forms of *ukemi*. The hand and wrist are not involved.

12.4.12 Udekimenage

"Projection with direct lever on the elbow" (extended). This technique produces a forward projection of *ukè*. With this lever, the elbow enters very strong tension, and if applied violently it can easily have a dislocation or fracture, but there is not involvement of the hand and wrist (Fig. 12.14).

Fig. 12.13 Imbalance obtained by applying the Techinage technique

Fig. 12.14 Lever at the elbow and imbalance obtained by applying the Udekimenage technique

Fig. 12.15 Imbalance obtained by applying the Sumiotoshi technique

12.4.13 Sumiotoshi

"Unbalanced with lever on the elbow" (flexed). Projection based solely on imbalance that does not endanger any articulation (Fig. 12.15). A strong energy applied to the internal side of the attacker's elbow causes the fall to the ground to be resolved with various form of *ukè* rolling or jumping patterns (Fig. 12.16) depending on the conditions and ability of the *ukè* (Fig. 12.16).

Fig. 12.16 Ukemi jumped to absorb the imbalance caused by the Sumiotoshi technique

12.4.14 Jiujigaraminage

"Projection with crossed arms." At the end of this technique, of which there are two versions (Figs. 12.17 and 12.18), the *ukè* is found locked with arms crossed and leveraged. By forcing the technique, you get a projection that will result in various forms of *ukemi*. This technique, especially in some variants, can be dangerous for the shoulders and elbows, but there is no involvement of hands and wrists.

12.4.15 Udegaraminage

"Arm control." This technique can be done in two ways. In the variant in which the *ukè* has the limb extended, the lever is applied only to the elbow and foresees a fall back (Fig. 12.19). In the most common version, where the limb is flexed (Fig. 12.20), the lever involves the elbow and wrist that will be folded in the palm way. This execution expects that the *ukè,* to quickly release from the lever, performs a jumping *Mae Ukemi*. Even in this case, an experienced practitioner who knows what he has to do will provide to *ukè* an useful assistance by simplifying the *Ukemi*, but a coarse execution that is likely to hold him inappropriately can result in an exaggerated wrist flexion with consequent damage.

12.4.16 Katagatame

"Shoulder immobilization." The execution of the *Nikkyo* and *Kotegaeshi* techniques can have the projection to get rid of the attacker quickly or, as the basic form is expected, his blocking on the floor by levering his shoulder, thus applying a form of *Katagatame*. However, this type of control on the shoulder can be obtained before landing the person and used to force it to the carpet in the prone position, thus transforming an immobilization technique into a standing technique (Fig. 12.21). The stress *ukè* suffers and the movement that he is forced to go down to the ground are quite similar to the *Ikkyo* technique, but in this condition, everything will happen in a more direct and resolute way. Being in the shoulder only, no consequences for the hand and wrist will be, but as for the *Ikkyo* technique, injuries to the contralateral hand can occur, especially in the *urà* version.

Fig. 12.17 Reversal of the shoulder and imbalance obtained by applying the Jiujigaraminage technique

Fig. 12.18 Lever at the elbow and imbalance obtained by applying the Jiujigaraminage technique

Fig. 12.19 Lever at the elbow applying the Udegaraminage technique

Fig. 12.20 Position of the hands in the Udegaraminage technique

Fig. 12.21 Spilling of the shoulder by applying the Katagatame technique

12.4.17 Koshinage

"Hip projection." This is not just a simple technique but a series of techniques that are realized in various ways from almost all forms of attack. Those who apply this projection take in contact their own hip with that of the opponent so that their center of gravity is lower than his. The *ukè*, unbalanced by this contact, finds herself crossing her body beyond that of the *torì* almost overwhelming it and ending heavily on the ground (Fig. 12.22). Occasionally, unexpert *ukè* can find themselves in the impact with the ground with the hand crushed under their pelvis, causing trauma or even fractures. As this is a very advanced technique, normally the projector manages to provide his or her assistance with a hand restraining arm and ensuring a lighter, more accurate, and therefore safer impact.

12.4.18 Kokyunage

"Projection with breathing." Even in this case, it is not a simple technique but an entire category of techniques that are realized in the most varied ways by the various attacks. The end result is always a rolling show of the *ukè*, which is very unlikely to have consequences on hands and wrists. However, if injuries occur, the projections apply the principles of the basic techniques already outlined. Kokyunage is a kind of point of arrival in Aikido's practice, and with their execution you can project very quickly by performing essential movements. The name suggests breathing because the fundamental condition for the good performance of the technique is running at just the right time, in perfect harmony with the energy of the attack. Breathing for those who attack, as well as for those who defend, is a key element because, if well coordinated with the movement, it emits maximum energy from it. The condition for proper performance of kokyunage is a clear awareness and an absolute mastery of breathing. This is achieved by starting with simple respiratory exercises and then moving on to the proper use of breathing by combining it with the movement. At a more advanced level, this path leads to a kind of practice that some define as "moving meditation." What he pursues

Fig. 12.22 Lifting and unbalance obtained by applying the Koshinage technique

through the study of aikido is not the submission of the other through technique but self-improvement through practice. In conclusion, we seek not only mastery but also control of our own emotions and mind.

12.5 Injuries Caused by Errors During the Execution of the Ukemi

The term *Ukemi* expresses a concept that can be translated with a "method to defend the body" in the general sense of undergoing a technique but more specifically when it impacts the ground as a result of a projection. The *Ukemi* are a set of techniques to defend the body. Is obvious that if this study will be tackled with method and rigor, the students will hardly report trauma and injury. However, incorrect execution for distraction, fatigue, or casualty is always possible. Hand injuries and wrists are virtually absent as a consequence of back and side falls; the only injuries in these bodily districts occur during the execution of *Mae Ukemi* (fallen forward). A rigorous *Mae Ukemi* teaching that puts security in the foreground is the use of both hands. Assuming a forward fall from the guard position with the right side of the advanced body and the right upper right arm, we will have rolling starting from the little finger of the right hand, then engaging the medial margin of the hand, forearm, elbow the right arm and shoulder. The movement then continues with the back that will contact the ground on a diagonal line from the right shoulder to the left hip. The lower left limb will be the actor of the last part of the roll, i.e., the phase in which you stand up and the last contact before being on guard again will be with the back of the left foot.

Having specified that for maximum safety you should use both hands, we will call "the rolling limb" the advanced (in the example the right) and the "limb of the support" the contralateral.

Returning to the example, the role of the left hand would be to download part of the body weight by placing the palm of the hand and using the entire left limb as a shock absorber, while the right, semicircular, facilitates the shifting of the center of gravity by causing rolling. In making this necessary preamble, we will say that the wrong support of the hand corresponding to the rolling arm is the almost exclusive cause of all the finger, hand, and wrist consequences found during the execution of the Ukemi.

12.5.1 Fingers and Hands Injuries

The casualty or distraction, usually produced by fatigue, can cause a wrong contact of the rolling hand, which does not rely on the solid media margin, but impacting the surface with the tip of the fingers. In this case, the fingers can be opened in a disordered way, i.e., the middle finger extended, while the other four fingers go in flexion. This disordered distribution of the load may cause dislocation of one or more fingers at the level of the proximal interphalangeal joint or metacarpal phalangeal joint or tendon ruptures. Only very rarely metacarpal or phalangeal fractures occur, and yet I have never had direct evidence during my experience. I emphasize that this type of injury occurs only when the impact of the fingers is perpendicular to the ground. Unfortunately, the traditional didactics, to speed up the *Ukemi*, teaches an entry into the roll, producing a rolling movement from the top to the bottom, which unfortunately makes this accident possible. In the didactics I have proposed in the "Ukemi Manual" to avoid this risk, and for other good technical reasons, it is expected that the hand of the rolling beam will go down without following a circular line from the top to the bottom but rather oscillating from behind to forward, while the propulsion to speed up and stabilize rolling is provided by the impetus of the lower opposing limb. An attentive didactic means that contact with the ground of the support hand always takes place using the entire palm of the hand. If this happens using only the fingertips, as many beginners do to avoid bending the knees, there is a consistent likelihood of dislocation of the thumb if the hand support is with the thumb facing forward rather than medially as it should be.

12.5.2 Wounds on the Wrist

The vertical descent of the rolling arm in the *Mae Ukemi* may also cause injury or fracture to the wrist if the support is reached with the back of the hand. The wrist will find itself in a strong hand flexion with the weight of the entire body to weigh on the joint. In order to avoid this damage, my teaching always provides that, in conjunction with the use of the rolling limb, there is in any case the support limb which performs optimally the role of damping and stabilizing the *Ukemi*, avoiding wrist injury in case of a wrong bearing of the rolling hand. Another event that can bring unpleasant consequences occurs when the practitioner, projected forward for insecurity or perhaps to avoid a companion or an obstacle, renounces to perform *Mae Ukemi* and falls stiffening his arms forward. With this dynamic, if the fall is very violent or the subject young or frail, the classic consequence is the scaphoid fracture, but it is also possible to dislocate the wrist or the metacarpophalangeal joints especially if after the impact of the hands, the body continues the forward movement falls with the chest to the ground beyond the support. With this dynamic, fractures of the ulna and distal radius may also occur.

12.6 Injuries in Practice of *Jo*

As a first observation, we will say that jo is a simple stick (of varying length depending on the practitioner's height, usually corresponding to the height of the ground of his armpit and with a diameter varying from 23 to 30 mm) but, if handled with expertise, can turn into a very effective weapon. It is an essential and therefore versatile tool that can be worn in various ways and is normally used to guard right and left from both right- and left-handed practitioners. It is used to bring tip attacks and shots on different lines and directed to various parts of the body. The maximum effectiveness and danger are in the tip attacks. This is determined by the fact that in real martial situations, the real targets for this weapon are fragile organs, such as the eyes and the throat, which are targeted by tip attacks. Injuries involving these districts are not relevant to the subject matter, so damages caused by tip attacks are not considered here. Those who cause injuries of our own interest are attacks on cracks that accidentally end up with striking the upper extremities: in general the anatomical elements injured are the fingers of the hand that holds the jo in the most advanced position, for example, the right hand if you are right guard. There are many types of shots taken on different lines and aimed at different targets (head, bust, lower limbs) that can be associated with various shots plasted and with different grips. This results in a very high number of possible combinations, but with regard to this publication, those who produce injuries are almost exclusively the head attacks. Attacks on the head are basically two:

Shomen (vertical shot from top to center of the forehead)
Yokomen (diagonal shot from top to bottom)

The parade that is achieved in defense of the high target is called:

Jodan (high parade to defend your head)

This parade can be done in two different ways depending on how *jo* is being challenged:

Jiuntè (matching thumb grip)
Yacutè (contrasting thumb grip)

The fact that the hand is hit is usually attributed to a wrong grip of those who defend that due to insecurity grabbing the *J*o with hands too distant between them and when lifting it to defend the head, the hand is too close to line of the slider. Another typical situation occurs when a parade is made tilting the *Jo* incorrectly, that is, the shot instead of slip away from the target converges to the hand of the defender. In this condition the fingers that receive the stroke are always the closest one to the impact between the two sticks and then the index or the little finger depending on the type of parade or handle. Synthesizing in terms of injury all can be focused on two fundamental situations. We will have that the combinations with parade handgrip in *Jiuntè* have in common the fact that the index finger is more exposed, while the *Yacuté* parade combinations put at risk the small finger. Fingers may be affected both at the phalanx and even at the knuckles. Damage will be greater or lesser depending on the violence of the stroke and the fragility of the affected person (young people or women will have more serious damage). The lesions found can be simple skin wound that is crushed between the wood and the bone, to the fracture that usually affects the phalanxes. The thumb is seldom affected, and if it happens it is always that of the hand that holds the *Jo* in a backward position. This type of injury occurs only in case of grossly serious parade mistakes.

12.7 Injuries in Practice of *Bokken*

Bokken is a wooden sword. It is the tool traditionally used by the samurai in training as it is too dangerous to use the sharply and deadly *katana*. *Bokken* reproduces the size, weight, and curvature of the Japanese saber, and, like for *Katana*, these three components are not fixed but extremely variable depending on the fencing school, the build, and the practitioner's preferences. On the *Bokken* as on *Katana* is mounted a hand protection that in Japanese has the name of *Tsuba*. However, in Aikido's practice, by martial habit, this protection is little used except during the execution of technical elements that put their hands at risk in a particular way. *Bokken's* handling differs greatly from that of *Jo*. First of all because the *Bokken* only deals with the advanced right hand, this condition is mandatory also for the left-handed ones that would

Fig. 12.23 Immobilization and disarming applying the Nikkyo technique

spontaneously oppose positioning the left forward[1]. *Bokken's* handling involves tip attacks but above all strokes on various lines, directed at all parts of the body. As already mentioned for *Jo*, hand injuries occur almost exclusively with blows to the head. However, with *Bokken* they are less likely than with *Jo*. The handle with very close hands diminishes the risks for the right hand which is, however, the most exposed and exclusively the one that is injured. Committing mistakes by running the *Jodan* high parade can cause injury to the knuckles and especially to the index finger. Even in this case, the damage can vary from the simple peeling of a knot to the fracture of a bone of the phalanxes.

[1]This is determined by historical reasons. All samurai handled the *Katana* by pulling it out of the sheath that had to be brought mandatory on the left side. This condition became necessary to prevent a samurai accidentally touching his sword with a similar caste crossing him in the street. For the same reason, traffic on the roads took place, and it still happens, keeping on the left side. Bumping another warrior belonging to another clan with his own weapon, even accidentally, was considered a very serious provocation that had the highest probability of breaking out a duel with as serious as unnecessary consequences.

12.8 Injuries in Practice of *Tantò*

Tantò is the wooden training knife. Its actual danger is limited to accidental hits that reach the eyes. To prevent damage, the tip is always smooth, so even a shot that touches a hand, performing a parade, is never injurious. Solutions to defend against dagger are simply variations of some basic techniques previously presented. The *Tantò* do not perform the projections for two good reasons: the attacker might hit when he is projected and replicates his action immediately after he has risen. So the *Tantò* attack techniques always require immobilization and final disarming. During their application, the *torì* must prevent that *ukè* passes the knife from one hand to the other. To avoid this, the only way is to force those who attack to tighten the grip on his knife, superimposing his fingers to that of the *ukè*. This condition must be maintained until the control of the attacker allows for safe disarmament (Fig. 12.23). Folding a wrist extensively while the fist is tightly clenched is more painful and potentially injurious of a similar strain caused with extended fingers. Techniques with *Tantò* generally begin to study at an advanced level in order to provide effective personal defense skills. This type of workout is generally practiced more martial, with fast and technical attacks carried out with great energy. The levers on the wrists already seen before, if applied to the knife defense, are generally more painful and potentially detrimental to the tendon-ligament structures of the hand and wrist.

12.9 Occasional Injuries

To be complete, let us consider those injuries that are relevant to the practice but not with technical execution errors or *Ukemi*. In some cases, despite everything being done correctly, the fingers remain caught in the partner's sleeves. The fingers that most often remain victim to this lesion are the middle and the little finger. Even the first finger can happen to this unfortunate coincidence by engaging in the side opening of the *akama* (the wide black trousers that the black belts wear, a symbol of the samurai warrior caste and which in Aikido is worn as a testimony to its noble origin). Other possible injuries are due to the crevices that are often created between the *tatami*. Victims of this disadvantage are usually the toes but also the fingers. It may happen in actions where the hand palm slipping on the mattress is expected to collapse into a slope or slit between the *tatami*, resulting in distortions at the level of the joints between the phalanxes. The most exposed fingers to this event are the average, which is subjected to compression traumas along the longitudinal axis, and the little finger, which can have a lateral dislocation of the metacarpo-phalanx joint. The movement called *Tenkan* is perhaps the most common and the most characteristic of Aikido. This shift causes the body to rotate backward by pivoting on the advanced foot. It may happen that the practitioner does not realize that his or her heel rotating at his shoulder strikes the hand (or sometimes the head or other parts of the body) of another practitioner who may be immobilized in a prone position. The impact between a heel, that moves with all the weight of the body, and a finger of the hand inevitably the finger breaks. Unfortunately, on the *tatami* often too busy, such accidents are frequent although rarely the consequences are serious.

12.10 Development of Chronic Diseases

After examining so many specific painful situations, we now say what is the main cause of suffering for the Aikido practitioner who trains with great passion and determination. The real problems are not usually attributed to a single trauma. With care and adequate rest, the individual injury can usually be recovered in a complete and timely manner. However, what complicates the things is the martial spirit that a true Aikido practitioner finds to possess and embody. The real martial spirit does not foresee convalescents, long or short, that they are: in the martial art you have to do with what you have. Of course the ideal is to practice when the whole body is intact and trained, when you are well rested, and when you do not have any stress that causes to take away the concentration. The difference with the athlete, especially professional, is enormous. If an athlete whose goal is to win a race, scheduled for months in advance, has an accident, he or she is concerned to recover as quickly as possible and to do so may be forced to rest if this is the only means to recover 100% of the performance. In Aikido the competitions do not exist, and since practice is the only purpose, it does not make much sense to interrupt it. The aikidoka is never obliged to provide a set level of performance, and the intensity of training depends solely on the person's will. The purpose is to raise their own limits, including the one to endure the pain. Establishing this, the fact to have an injury to a part of the body is no longer a limit; you train by trying not to worsen the condition but to train yourself. Physical limitation can become an interesting challenge stemming from the question: "See how I can do the same despite the pain in my shoulder or knee." This aspect of martialism is really interesting and perhaps more than any other forms, as the sense of sacrifice, self-discipline, self-esteem, and so on, in a word the spirit! The aphorism that says "a warrior without an arm continues to fight with the another" summarizes all the speech. Obviously, this behavior is ideal for chronic problems, and in fact, chronic pain is the real problem. Tendinites that last for months and even years are on the agenda. Consequences due to cartilage wear mostly affect the knees and shoulders but to a certain extent also affect the wrist and joints of the fingers. In the predisposed at the level of the wrists, tendon cysts may develop, which also tend to recur. One aspect that most of these problems share is dressing. On the *tatami*, the panacea is the paper ribbon, the one that is bought in ironmongery, a few laps to form a semirigid bandage to limit the movement and start again. The real aikidoka never stops!

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13 Functional Recovery of the Combat Sport Athlete: Wrist and Hand Injury—from Post-rehabilitation to the Competition

Davide Carli

13.1 Motor Function Recovery

At this stage, we must respect all the articulations that have just begun the movement but are still unable to express their maximum potential and safety.

During post-rehabilitation recovery (motion recovery phase), the athlete's structures are not yet ready for physical effort, so the exercise safety should be fundamental.

Before determining the intensity to be taken in the program, it is mandatory to identify and evaluate the risk factors with the physician.

At this stage, it is important to choose the right degree of intensity and the difficulty of managing the training movement.

After the physician's approval, you must establish a communicative feedback with the athlete about the perception of pain, fatigue, intensity, etc. It will also be important to inform him about the risks of incorrect actions so that he immediately acquires his own psychophysical control.

Recovery must not only be physical but also mental. As the athlete succeeds in handling intense and difficult exercises, he will also increase his safety in the athletic gesture.

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Of course there is a load progression that suits each situation, as described below.

Minimum load exercise takes on important significance in the first phase of recovery:

- It respects the healing of the tissues injured or just operated.
- It promotes increased capillary density, thus improving metabolic exchanges.
- It assesses the athlete's psychological and physical response in overloading exercises.
- It permits the recovering of both the healthy and healing joint structures (bone thickening, cartilage hydration, connective remodeling, connective elasticity, etc.).
- It improves active mobility, strength, and resistance.

Exercise with maximum loads should be used at an advanced stage:

- It increases trophism and muscular power.
- It improves the neuromuscular recruitment capacity of the motor units that cluster white fibers.
- It increases discharge frequency of the motor unit; the sum of the motor action potential leads to a situation called "tetano" which is a characteristic of the maximum force.
- It affects the healed articular structures to support important stresses.
- It promotes joint stability.

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- It determines an important hormonal response, especially with testosterone, GH, IGF-1, and cortisol.
- It influences the muscle coordination: intramuscular coordination, synchronized intervention of all muscle fibers and intermuscular coordination, synchronized activity of all synergistic muscles and fixators.
- It determines the modulation of antagonist muscles during the movement: the mechanism of "reciprocal inhibition" induces the relaxation of antagonist muscles by reducing the resistance to be gained while performing the athletic gesture.
- It induces the increasing of energy reserves, mitochondria, and capillary density.

Therapeutic exercise should therefore be considered as a precise planning of movements to be carried out at varying intensity and amplitude while keeping postures ideal for the specific sport.

The goal of retraining (motor or functional recovery) is to return to perform the highest performance safely.

The motor conditioning must be performed by working on different physical parameters:

- Articular mobility
- Muscle conditioning (strength, speed, and resistance)
- Articular stability
- Coordination and neuromuscular control (technique, ability, agility, etc.)
- Balance and proprioception
- Postural equilibrium
- Cardiopulmonary capacity

The first aspect to be considered is the recovery of the joint mobility, since the joint should be free to move without developing frictions and tensions.

In this way the load will be distributed throughout the range of motion, without straining structures of the same or other joints that take part in the athletic movement.

However, without the force that guarantees both the joint estate and performance, athletic gesture would lose its meaning, so it is important to gradually regain the necessary muscle capacity in order to continue with the functional recovery program.

In the first step of conditioning the force, at the same overload, it will be easier to control the eccentric phase. In this way, an initial level of strength and neuromuscular control can be developed to start the exercises even at a concentric stage.

Of course, to move freely, in safety and developing the maximum performance, the various body segments require joint stability and coordination. In fact, if you have not yet recovered good coordination, some muscles will replace the work of a muscle group and then excessively overburdening and then getting injured.

With proprioception exercises, control of balance and posture, you will be able to have a better perception of your body in space, thus gaining all the potential you have, minimizing the risks of recurrences.

In sports, more and more important performances are required even in extreme condition of fatigue. Therefore, the development of cardiopulmonary capacity takes on a significance; in fact it allows to perform the continuous repetition of the athletic gesture while maintaining a significant degree of strength and control.

As you proceed with retraining, you will need to carry out verification tests (mobility, performance, stability, control, etc.) to better understand the progress of the athlete and especially to see if it has difficulty to improve in some physical aspects.

Subsequently, the interpretation of the acquired data with the tests becomes significant. In fact, based on this, it is necessary to reprogram the functional recovery by working on different parameters:

- Load intensity
- Range of motion (initially you will only use the non-painful movement arc)
- Work volume (serial number and total repetitions)
- Training sessions
- Rest between the various series and exercise sessions

– Duration of training (as well as volume, duration is influenced by different physical activities: coordination, cardiopulmonary, mobility, etc.)
– Order of exercise (decides the conditioning sequence of the various muscle groups)
– Periodization of the various training cycles (determine when to prioritize some motor skills compared to others by performing loads and discharges of work)
– Speed of execution
– Type of exercise (static, concentric, eccentric, plyometric, unstable, highly coordinated, etc.)
– Stabilization of the exercise (using different techniques you can decide when to stabilize the proximal or distal articulation for the strategic purposes)
– Nutrition and food integration (work must be supported by a balanced supply of nutrients)

The interpretation of data obtained through tests has a high significance in understanding the trend of motor recovery. However, to understand its appropriateness, some questions should be considered:

– Are you experiencing pain during the exercise?
– What is the level of irritability and healing of the tissue operated?
– After load exercise, are you feeling pain or are you noticing effusions in the body parts affected by healing?
– Has a cooldown phase been performed after training to help relax the joint structures?
– Are the work volume, intensity, frequency, and difficulty of exercise adequate at the moment?
– Have stability, proprioception, balance, posture, and coordination deficits been totally recovered?
– Is the range of motion totally recovered without pain or reduced?
– Is the pain felt more in the eccentric or concentric phase?
– Do you still have deficits in physical performance?
– Do these identified deficits lead to future injuries?
– Do painless exercises exist and are equally effective for the motor recovery?
– Have you analyzed all the types of metabolic stress that identify the competition?
– Are we sure the athlete has performed the exercises correctly and impeccably with the supervision of experienced staff?
– How long do we have to achieve maximum performance?
– What are the goals of the athlete?

As you can notice, the parameters to be monitored during a motor recovery are so many, and only a proper interpretation of the same will guarantee an optimal motor recovery.

13.2 The Motor Recovery and the General Principles of the Training

A good reeducation program needs organized and structured diagrams with logic that respect the physiology and biomechanics of the human body without neglecting the delicate structures that are still not perfectly recovered.

The athletic trainer, in order to achieve qualitative conditioning aimed at achieving the specific goal, will use a progressive intensity in the most appropriate exercises, alternating with the required recovery. To achieve this, *the general principles of training* should be observed:

– *Continuity*: The benefits of training tend to decrease or cease when training sessions are reduced or interrupted, while constancy promotes important organic adaptation.
– *Progressiveness*: Workloads must always be gradually increased to allow for adaptation of all biological structures, especially the injured ones. Progression, moreover, not only affects the intensity of physical overload but also the resumption of technical gesture; it is necessary, in fact, to become the master of complex gestures to increase performance without incurring the risk of recurrence.
– *Alternation*: High intensity, considered both within the same training session and in the

total length of the retraining period, should be alternated to recovery moments or changes in the load. On the contrary, if you always maintain high intensity, you can seriously overload the organic structures, risking not reaching the goal desired.

– *Specificity*: Careful consideration must be given to the motor activity where motor recovery is required, by examining all the parameters and technical gestures on which the competition is being made.
– *Variability*: The execution of multiple and varied targeted exercises avoids the creation of boredom, allows better balance of posture, multilateralism respect, and acquires a broader range of automatisms.
– *Individualization*: Each subject has its own features that the functional recovery program must take into account to allow the athlete to fully develop his potential in total safety.
– *Cyclization*: The human body is not a machine; therefore, to achieve the right psychophysical state at the time of the competition, a program is built on loading and unloading times.

13.3 Considerations on Retraining

In order to develop the necessary bodily adaptations to the training loads, in order to achieve the desired goal, the recovery times must be respected.

The stress to which our body has undergone is called "stimulus." A psychophysical adaptative response will inevitably follow it. So the stimulus becomes the fundamental element for the progression and improvement of motor recovery and then of maximum performance.

To achieve the desired adaptations, several parameters must be analyzed and calibrated during the program:

– Quantity (work volume)
– Intensity (percentage of training load in relation to the limit)
– Density (amount of stimuli per unit of time)
– Quality (stimulus specificity)
– Recovery organization

The amount of work is related to the serial number and repetitions performed in the training session.

Initially, when workloads are very low to respect the healing structures, the volume of work can be high. Indeed, depending on the case and always respecting the injured tissues, more sessions can be repeated daily to facilitate a better neuromuscular adaptation and coordination.

The articulation should be "attacked" with a job that involves multiple diversified exercises.

Generally the first should be the ones that involve more muscle mass, but this must be verified as a function of the lesion. However, the various types of exercises, working in multiple angles, must "strike" different muscle beams so to not overload only one. To give a purely indicative idea, a recovery program could start with 10 sets of 20 repetitions divided into at least three different exercises.

Usually the progression of the intensity to be taken during motor recovery is the most difficult aspect to analyze, as each type of lesion has its own healing time.

First of all, it is necessary to confront the surgeon who has treated the lesion to better understand the timing, the difficulties, and the risks and then examine the articulation with tests and interpret them by putting all the questions described above.

As the intensity increases, the work volume will inevitably decrease (Fig. 13.1).

Density of stimuli can be increased by decreasing the recovery times or increasing the running speed. In order not to go to recurrence risks, this parameter needs to be increased only after gaining the right degree of strength.

The quality of the stimulus must reflect the psychophysical effort and the metabolic aspect of the competition.

In this case, the specificity of the stimulus will be sought through the execution of functional exercises that identify the athletic gesture. However, as for the density, even for the specific performance required by the competition, it is

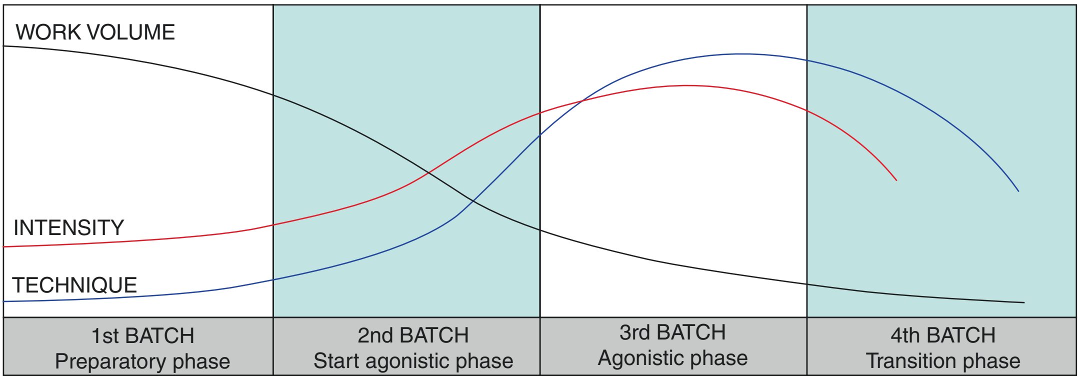

Fig. 13.1 Trend of the curves related to the work volume, intensity, and training of the technique, according to the different phases of motor recovery

best to recover a general form with a good foundation of strength.

Positive adaptations to physical and mental stress will be obtained when the volume and work intensity are proportional to the recovery, while an excessive load training will definitely result in injuries of the healing structures beyond overtraining.

As mentioned earlier, training sessions can be repeated several times a day at the initial stage, while once recovered a decent physical fitness, the recovery intensity will rise considerably, and hence it will be essential to give important recovery to the structures in object. On average, our body takes about 48 h to recover a medium-to-large effort.

This data highlights how difficult it is to schedule preparations that consider both motor and technical training at the same time without to fall in overtraining. The useful adaptation is obtained when overloads are proportional to the athlete's psychophysical abilities and periodized so as to allow the body a sufficient mental and physical recovery. A too abrupt increase in overloads will only create blocks in progress and/or new injuries.

If you take as a conventional reference the week, you will have to alternate low-intensity technical training with others where you will use important overloads.

It is advisable to provide at least 1 day of absolute rest (usually on Sundays) so that the athlete does not accumulate excessive psychophysical fatigue.

A program with multiple daily training sessions might be also created so that an additional full rest day in the week, like Wednesday, might be chosen in addition to the usual Sunday.

13.4 The Final Stage of Motor Function Recovery

After selecting and evaluating the basic parameters of functional recovery (volume, intensity, density, specificity, and recovery) and developing the various conditional capacities, one must advance by conditioning the skills and technique.

Skill training is different from the technical one. The first refers to the athlete's skill in performing a particular task with timing and precision; the second concerns the ability to properly perform a technique, but not to do it at the right time and with the necessary dexterity. Therefore skills and technique are complementary.

The technical goal is to build advantageous levers that can guarantee maximum effectiveness in order to achieve the sporting result.

Instead, skill is highlighted by the athlete's style, talent, and ability to apply the technique in a variety of situations with precision, ease, and timing, making simple even the most complex movements.

The technical training is taught by the master, who will try to personalize it in the best way according to the athlete's characteristics, but the ability is conditioned under the control of the athletic trainer following the motor recovery program.

The athlete will then use a number of functional sports-specific exercises to reacquire the needed skills; these exercises may reflect only one part of the technical movement (partial method) or entirely (complete method).

By using the partial method, it is possible to work directly on the weak part of the movement, but it may be more difficult to recompile the entirely athletic gesture, especially if the skill that is being trained affects the explosive power. In this case the choice is made by the athletic trainer and the instructor based on the learning abilities that the athlete shows. Allowing an athlete to return to the competition without having acquired the right automatisms on skill and technique might determine a number of uncertainties in the athletic gesture that would be difficult to remove, as well as a decrease in performance and an increase in risk injury.

Thanks to a perfect synergy and following a proper planning, the trainer and the instructor will have to try to get the athlete the best skill and optimal technique to support a competition.

The level of attention and ability to learn skills and techniques varies in athlete according to genetics and personal motivations. The athletic trainer must be able to motivate the athlete and understand when his level of attention begins to decrease. In this case, in order to maintain the concentration and avoid the occurrence of boredom, it must be tried to change the exercise (principle of variability).

Summing up this first part, the motor recovery program might be formulated so as to provide the correct physical stress without interfering with the healing of the injured tissues and allowing a performance increase.

The objectives to be achieved through the exercises can be summarized in:

- Conditioning exercises
- Learning exercises

In the first case, exercises are designed to develop the conditional capacities of the body in the most functional and specific possible way.

In the second, it might be focused on learning the technical gesture and the development of motor skills that will allow the athlete to express the maximum potential.

13.5 Details About Motor Capacities

To recondition the athlete to the return of maximum performance, all systems and equipment, with a specific synchronization, must work as a single entity. To achieve this, all motor skills must be properly restored.

First of all it might be sure that the athlete has reached a good general condition, recovering each individual motor capacity separately. Subsequently, it should be needed to concentrate the attention on the functional aspect, that is, it should be payed close attention to the search for movements that have similarities with the technical gesture, and then use them as profitable exercises to enhance the technique itself.

During the retraining it will recreate the same stresses as competition. The athlete will be very sensitive to the improvements that will be obtained, and especially the risks of recurrence will be minimized.

Motor skills are divided into *conditional*, *coordinated*, and *joint mobility*.

The first stage of retraining is directed at the development of individual conditional capacities: endurance, strength, speed, and mobility (in the latter, only the soft tissues, controlled by the nervous system, can be conditioned, while the anatomo-structural part is given by Mother Nature and unconditioned).

Then it is necessary to start conditioning the general coordinating capacities and then the more specific ones: coordination, balance, agility, dexterity, skill, technical combinations, specific automations, reaction, anticipation, motor creativity, etc.

As soon as the athlete returns to a state of sufficient condition, intensity and difficulty exercise will increase with technical, tactical, and strategic training of specific sport.

Therefore, conditioning the various motor skills provides the body with the necessary assumptions for functional recovery and improvement of the technical gesture.

Conditional property is in detail.

13.6 Mobility

Mobility (or flexibility) is the ability to perform movements at the maximum joint width.

It does not represent a real capacity for conditioning because it depends on both a structural component acquired at birth (form of joints, type of connective tissue and muscle), as well as from a tissue and nervous component that identifies the one that can be improved with exercise.

After an accident, mobility declines significantly and represents the first quality to be recovered (passive and active mobility).

Reconditioning the flexibility, the athlete will be able to better distribute his strength to more muscle districts, thus avoiding overloads and decreasing the risk of recurrences, furthermore, increasing the movement's excursion and the time of strength duration (eccentric gesture loading).

This higher propulsive thrust will result in an indirect increase in speed. In fact, the result of force for the time of application to a specific movement is physically defined "impulse" ($I = F*t$).

The reconditioning of the flexibility also indirectly influences the ability to achieve greater work. Returning to physics, the work is defined as the result of the force for the space in which it is applied ($L = F*s$), consequently increasing the movement's excursion; force will be applied for greater space, thus increasing the work done, which is essential to obtain a good motor recovery. In this way, the athletic gesture will have more strength and control particularly for the last important degrees of movement.

At this point it is also useful to introduce the concept of muscular elasticity, that is, the ability of a muscle to release during the elongation phase and then return to its physiological length without suffering any damage. Tissue elasticity is important in all gestures that are performed quickly, especially when the movement is performed by a pre-stretching (eccentric loading) followed by an explosive action (concentric contraction). Elastic reconditioning of the tendon-muscle system is a fundamental prerequisite to get back quickly to an athletic gesture. Firstly, it should avoid bouncing movement, slowly reaching the maximum excursion. Then, gradually and depending on the magnitude of the recovery, it will be necessary to recondition the elasticity at higher speeds to reproduce the stresses of the competition.

13.7 Strength

Strength is the capacity of a muscle through a voluntary contraction, to win an external resistance.

Force must not be seen only as a "brutal act" useful to raise a maximum load; indeed it must be considered as a basic quality upon which to rebuild its entire physical condition. The force allows the athlete to win the best external resistance and therefore spend less to make the same move. As a result, the athlete will be able to impress even more acceleration and speed at the same time with greater control, because the athlete is injured predominantly in the corner of movement where he has little strength; thus reconditioning this quality significantly reduces the risk of recurrences (Fig. 13.2).

The strength depends on several factors, but the first place, decided by Mother Nature, is the genetic patrimony. In fact, the latter determines the percentage of white (red) and red (slow) fibers present in a muscle. At parity of genetics, the

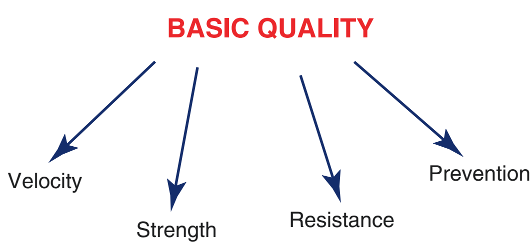

Fig. 13.2 The strength is the fundamental quality base for the state of form

greater the cross section of the muscle, the greater the strength that the same manages to express.

Apart from the muscular structure, strength also depends on the ability with which the nervous system transmits high pulse frequencies to the drive plate (a structure that acts as a link between the nerve and the muscle).

Coordination also plays an important role in the development of strength.

In fact, "intramuscular coordination" is defined as the synchronous activation of the various muscle fibers present in the muscle itself, while "intermuscular coordination" is the simultaneous participation of all the synergic muscles in the technical gesture.

By training the intramuscular and intermuscular coordination of the movement, the strength increases at the same time.

By learning the athletic gesture, it is also possible to increase the relaxation of the muscles that are antagonizing the movement, thus eliminating major frictions that reduce expressive strength. Especially when it comes to strong strength, it is also influenced by energy reserves. It will be very important to plan a nutrition that will keep you stocked. Strength training is very challenging for the body, so it is necessary to change the intensity to avoid accumulation of fatigue impossible to dispose of, both during the training session and throughout the entire work cycle.

The repetitions must be few, while recovery between the operating ranges, depending on the type of force required (maximum force, fast force, strength, explosive force), must always be long enough to allow the movement to be repeated with a "sub-maximum intensity." To be increased, the force requires two or three weekly training sessions, while only one session per week is enough to keep the results achieved.

13.8 Speed

Pure speed occurs during a movement against a minimal external resistance and only before the fatigue is reached.

If you continue to repeat the movement even after fatigue, you are already entering resistance training, because pure speed is the ability to make a technical gesture as quickly as possible.

This is the most difficult quality to recover after a trauma, just because you have already acquired an important mastery of the technical gesture.

To make matters more complicated, this conditional capacity is hardly incrementable in a direct way, as it mainly depends on the nature of your nervous system and genetic makeup. So to achieve good speed conditioning, it is necessary to increase it mainly indirectly, i.e., by acting on other components: abilities, power, resistance, mobility, and motivation.

The skill training will allow the athlete to develop more coordinated and quick engine designs; conditioning the force increases the potential of white fibers (fast moving members), thus allowing the athlete to more easily overcome external resistances; the greater the resistance gained, the later the sense of fatigue that limits speed; the force product for the time it is applied to a motion is defined as "impulse or propulsive thrust" physics ($I = F*t$).

Finally, only a well-motivated athlete will be able to find within that emotional thrust that will allow him to go back and seek his own limit.

Considering that different motor skills are mutually beneficial (the enhancement of physical quality will also indirectly contribute to the increase of another), it is very important to condition them all without any exclusion in order to guarantee return to specific performance.

In the case of speed recovery, the exercise must not exceed 10 s. And the next series will have to be executed with a tenfold rest period to that of the repeat itself (e.g., 6 s repeat, 60 s recovery).

13.9 Resistance

Resistance represents our body's ability to prolong physical work over time and with efficiency.

The resistance is further subdivided:

– General resistance occurs when you have an interest in multiple muscle groups involved in carrying out continuous work.

– Local resistance identifies the ability of a single muscle district to perform a lasting job.
– Specific resistance is the most interesting thing for the athlete, that is, the ability to repeat the athletic gesture of the disciplined course efficiently.

Resistance depends on several factors: metabolic, neuromuscular, coordinative, proprioceptive, and so on. So, to recondition this physical ability, you will need to train more organic qualities: by conditioning the strength, you can win and contrast the external resistances more easily; by increasing the efficiency of cardiocirculatory and respiratory systems, the ability to use energy and oxygen substrates is improved, a key prerogative for developing resistance; at mental level, it is crucial to develop insensitivity to fatigue and the ability to maintain long-term attention so that you can control the technical gesture without mistakes.

Organic adaptations, however, are very specific and directed mainly to the muscle groups involved in the movement.

In sports where a quick gesture (such as combat sports) is required, the resistance reconditioning sessions should not be too long and run according to the repeat system. The best results are achieved with repeated sessions that do not exceed 40 min (can reach up to 60 min if the athlete particularly sins in the resistance). Above the stated time, the athletic gesture will slow down significantly, and the result will be the development of a slow motion.

Using functional exercises and alternating slow phases (slow system), you can develop specific strength without slowing of the gesture speed.

13.10 Coordinating Capacities

Coordination capacities represent the organization, modulation, and control of the various movements of the body in the surrounding space.

It is important to start conditioning the coordination of the conditional capacities (mobility, strength, speed, and endurance) in order to stimulate the learning of roughness automatics, which will become perfected and then instinctive, over time.

The attainment of total mastery of the technique (the ability to perform automatically and properly a particular sports technique) is the ultimate goal of physical training and must be sought through a specific training.

Coordinating ability might be conditioned by a block method in which the technical gestures are repeated individually block after block or by a random method in which the various techniques are randomly requested.

The block method best suits in a first phase, while the random method, stimulating the nervous system more, is the most evolutionary stage of the athlete.

As the training proceeds, technical gestures will have to become increasingly complex and be executed starting from different positions and using unstable soils support.

Another parameter that significantly affects coordination ability is the speed. In fact, by modulating the speed of execution of the same technical gesture, the order by which the muscle groups are activated is also different.

If the technique is learned with a different speed than the one in the race, the athletic gesture will be uncoordinated.

In asymmetric sports, the scientific literature argues that by performing a technical movement on both sides, the coordination capacity is increased by a “drag” effect, but I think it is necessary to consider that in this way the working times should be doubled with significant reduction of the recovery times.

We suggest to use this method of training when we are working with injured athletes to be recovered or in the transition periods between one league and the other.

With functional training, you are able to train both the coordination and the conditional capacities at the same time, thus increasing dexterity (motor skills to coordinate the complex movements, quickly and precisely).

The choice of functional exercises should be sought by decomposing the technique in various movements to be used as a workout; thus no new motor gesture will be run by the athlete as an absolute novelty but will already be acquired in relation to the experienced motor skills in the workout.

The learning process is very demanding and begins by selecting the information from the immediate memory; then they will pass into short-term memory that will process them and formulate the required technical action. The continuous repetition of the described process will then allow the motor pattern to be fixed in long-term memory. At this point, every time the same stimulus is resumed, the motor information inherent to the previous experience will be reused in the long-term memory to be used quickly and automatically.

With the experience, therefore, the athlete will accumulate a wealth of useful informations to improve the technique and make it more automated while reducing energy costs (Fig. 13.3).

To put into practice what has been said before, it is necessary to develop dexterity by simultaneously operating on three different neuromuscular parameters:

- Proprioception (or deep sensitivity) represents the perception of movement and position of one's body in space.
- Executive timing, i.e., the ability to execute the required gesture at the right time.
- Motor intelligence, defined as the ability to shape the technical gesture necessary for the situation.

Speed is also an important component to increase the coordination difficulty, so it has to be taken into account for the purpose of improving dexterity. The same exercises must be repeated at different speeds and with different loads. This creates imbalances induced by the increase in the amount of motion (mass x speed) of the displaced

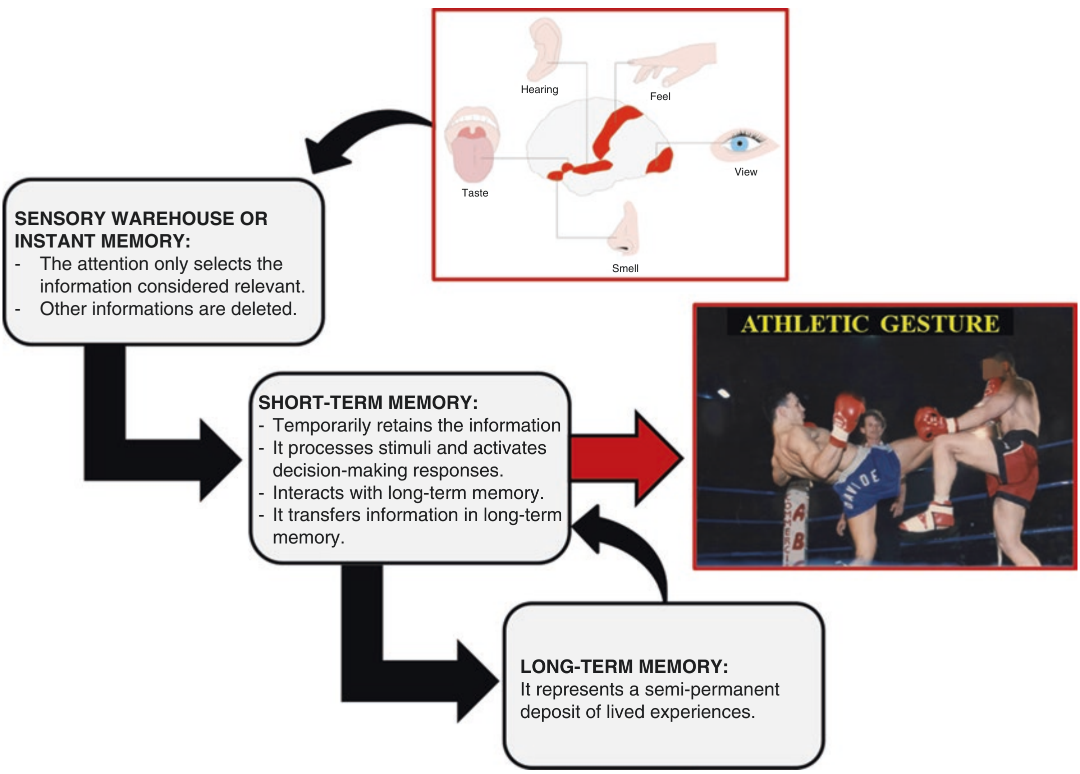

Fig. 13.3 Processing of the stimuli and creation of motor response

masses and learns to accurately control the dynamic equilibrium.

In order to increase reflex readiness (a fundamental component of dexterity), exercises should also include signals induced from the outside, where the athlete learns to tailor the response quickly.

The trainer, at the same time as doing the exercise, will then ask the athlete to take, avoid, reach, launch, etc. an object in a precise and controlled manner or simply ask him to answer to the verbal signals of the instructor.

More diversified will be the external stimuli and the motor schemes the athlete can automate, greater responsiveness and motion control, respectively. This is because the signal to the athlete will be an input already known, as well as the technical mechanism.

13.11 Considerations to Organize the Training Program

When the athlete is healed from the injury, before proceeding with the organization of the functional recovery program, it is important to carry out evaluations. The following diagram shows the main variables to consider (Fig. 13.4).

Of course, the protocols described do not have to be seen as miraculous recipes but as general job directions that will then have to be customized depending on the athlete you have.

Once you have evaluated the athlete and depending on the target, you need to plan training sessions so that you can search for the desired organic adaptations.

EVALUATION	*INDICATION*
State of form	The first step, excluding the pathologies, is to create a state of general form to build the goals.
Presence of deficit	Recover the missing part or rebalance the defect, using either asymmetrical or symmetrical exercises.
Presence of motion limitation	Recover all the possible passive and active motion (pay particular attention in the evaluation of the structural block).
Psicological status	Training, as well as useful, should be pleasing in order to generate positive emotions that reinforce enthusiasm
Pain or Irritation	During the exercise pain should always be respected except when it is caused by the rigidity and lack of elasticity, in which is useful to force the stretching gradually.
Overload	The choice of type of resistance (free body, elastic, medical balls, dumbbells, barbells, isotonic machines, etc.) must be assessed by maximizing personal abilities and minimizing the risk of personal injury
Assistance	Assess whether the person's abilities are appropriate to the technical difficulties of the exercise and provide the necessary assistance

Fig. 13.4 Physical evaluation to plan the functional recovery program

To clarify, I have set up a scheme that can help you to choose and execute the exercises (Fig. 13.5).

The athlete, who is healed from the injury and has reached a state of basic condition, must then begin a functional recovery program that will take you to recover the maximum performance.

Initially, a low intensity and a high volume of work (high number of repetitions and series) will be used, then progressively to a high intensity and low work volume (reduced number of repetitions and series) and athletic gesture resumption. During this process, the person should try to figure out which range of repetitions and series gets the maximum gain. In Fig. 13.6 you will find the standard parameters that can be used as a reference to understand the serial number and repetitions most suitable for your functional recovery program.

TRAINING FEATURE	*ORGANIC ADAPTATION*
Low repetitions	Neuronal adaptation
Average repetitions	Phosphatic adaptations and increased protein synthesis (myosin and actin)
High repetitions	Increase in size and number of mitochondria and capillaries
Low velocity	High and prolonged mechanical stimulation leading to the creation of new proteins
High velocity	High nerve stimulation leading to maximum recruitment of white fibers
Long recovery between the series	Increase in testosterone secretion
Short recovery between the series	Increase inGH secretion
Technique of intensity	Mechanical stimulation in addiction withmaximum recruitment of muscle fibers and maximum phosphatic depletion

Fig. 13.5 Organic adaptations according to the different training features

TARGET	REPETITIONS	SERIES	INTENSITY
• FITNESS	15-20 repetitions	1-3 series;	Moderate
• RESISTENCE	15-20 repetitions	2-5 series;	Discreet
• HYPERTROPHY	8-15 repetitions	2-5 series;	Sub-maximal
• STRENGTH	6-8 repetitions	2-5 series.	Sub-maximal; maximal

Fig. 13.6 Benchmarks for repetitions, series, and intensity

It is necessary to always check all the parameters that identify the motor recovery in order to reach the goal in total safety (Fig. 13.7). Therefore, you will need to customize a functional strategic recovery depending on the lesion and the desired result, modifying training parameters based on the healing state and reached form.

Depending on the biological component you prefer, you should have to use a different overload method.

For example, if the same muscle group is intensely and continuously urged, there is a buildup of lactic acid. Under these conditions, the energy substrate used is glycogen.

As a reaction, the body will tend to increase the stock of the latter substrate in a proportional manner to the production of lactic acid. In fact, during recovery, the body will tend to adapt by increasing the glycogen stores needed for intense work (SAID principle: specific adaptation to forced labor).

DESCRIPTION
INTENSITY: It refers to the extent of the load used for each repetition that should be progressively increased to give new stimuli (principle of overload) .
VOLUME: It is the result obtained by adding the series, the repetitions and the load; it represents the total work of the training. There should be an inverse proportional relationship between number of series, repetitions and load intensity (principle of overtraining).
FREQUENCY: It represents the number of training sessions per unit of time. As you improve with intensity, you should decrease the frequency of workouts (principle of supercompensation).
DURATION: It represents both the duration of the entire program (macrocycle) and that of a single training session in association with the work volume. Basic variations become the mode of execution (slow or fast) and the recovery times between the series.
RECOVERY: It represents the pause between the series and the training sessions. The higher the intensity, the longer the pauses between the series and the recovery times between the workouts (the principle of supercompensation)
PERIODIZATION: The human body is not a machine that can always go to the maximum, so the sporting season must be cycled with loading and unloading moments. The athletic trainer's duty is to coordinate the peak stages with the period of the competitions.
EXECUTION: The mode of exercise (slow, fast, controlled, intense, functional, etc.) should be organized with the other parameters described so as not to push the body too much (the principle of overtraining)
STABILIZATON: To do an exercise using the maximum potential you have, you need to immobilize and stabilize the proximal part of the muscle you want to train (fixed point principle).
ALIGNMENT: In order not to overload the joints in an abnormal way and to center the work on the desired body district, the direction of movement must be aligned with that of the muscular fibers that you want to solicit (principle of fan arrangement)
FACILITATION OF THE MOVEMENT: The kinetic chains intervenes in exercise as matched and facilitated

Fig. 13.7 Fundamental parameters for motor recovery

movement. Coupling to the open chain creates feed-back facilitations between the extensions, abduction and external rotation movements; however, according to the closed chain, positive feed-backs occur in the flexion, adduction and internal rotation movements

MECHANICAL DISADVANTEGES:* *It describes how a bi-articular muscle that crosses the same articulation of a monoarticular muscle can be placed at a mechanical condition of disadvantage by pre-shortening it when you want to use the strength of the monoarticular muscle.

***CHOOSING AND SETTING:* High muscular synergy exercises should be preferred, starting with movements that stimulate the center of the body (basin and trunk) first and then outwardly (limbs) in the centrifugal direction; supplementary exercises should instead be included in the day-to-day card or added only if there is a need for more specific muscle work (rehabilitation or performance)**

***MOBILITY:* Muscle retraction should be prevented by choosing intensity in exercises based on the person's ability to use the total range of motion (ROM) without any risk of injury and performing a proper stretching at each training session.**

Fig. 13.7 (continued)

In addition, the intensive load determines the micro-limbs at the muscle structure level that will then be repaired in the supercompensation phase, stimulating a higher protein synthesis.

In conclusion, elevated lactic acid production levels are associated with an increase in endogenous GH production, a hormone that significantly affects protein synthesis.

With this example I highlighted the cascade of events that can be set up during a training method. So by varying the typology, you can get many benefits in the direction you want. In the following diagram, I showed the biological modifications according to the training method used.

13.12 How to Make a Functional Recovery Microcycle

Once the structures are healed, the levels of mobility, strength, resistance, and coordination that identify the competition must be reestablished.

To achieve this goal, it is very important to choose the distribution of training units, both on day and week (understood as a microcycle). In fact, the planning of training units must have the right logic. Physical stresses, especially those related to the same types of training, should not be overlaid; in fact, they must be planned to ensure proper recovery.

That is, if a maximum strength training is done every day, or a maximal strength training followed by a speed training, the body cannot recover. Therefore, high-intensity training sessions (maximum strength, speed, and power) should not be distributed extensively.

To make some clarity and give some general information about the weekly microcycle, I have proposed a simple demonstrative example (Fig. 13.8).

In the above example, I have planned training units using two daily sessions (morning and afternoon), but you can also use the same compilation in one session; the important thing is not to exceed in terms of time and intensity. In a training session, physical conditioning should not exceed the hour, while learning (technique, skill, etc.) can be extended for longer if it is done at low intensity.

Whenever possible I personally prefer to distribute more training units on the same day and then devote 2 full days to recovery (Wednesday and Sunday), thus avoiding accumulating excessive fatigue.

The conditioning of force, speed, and power must always be performed first (both as an order in daily sessions or as a sequence in the same training) so the body can express all the potential

Timetables	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Morning	Strength	Mobility		Velocity	Resistance	Psicology
						Ability
Afternoon.	Ability	Resistance		Technique	Ability	Intensive Resistance
	High Intensity	Average Intensity		High Intensity	Average Intensity	Medium/High Intensity

Fig. 13.8 Example of microcycle to conditionate the resistance

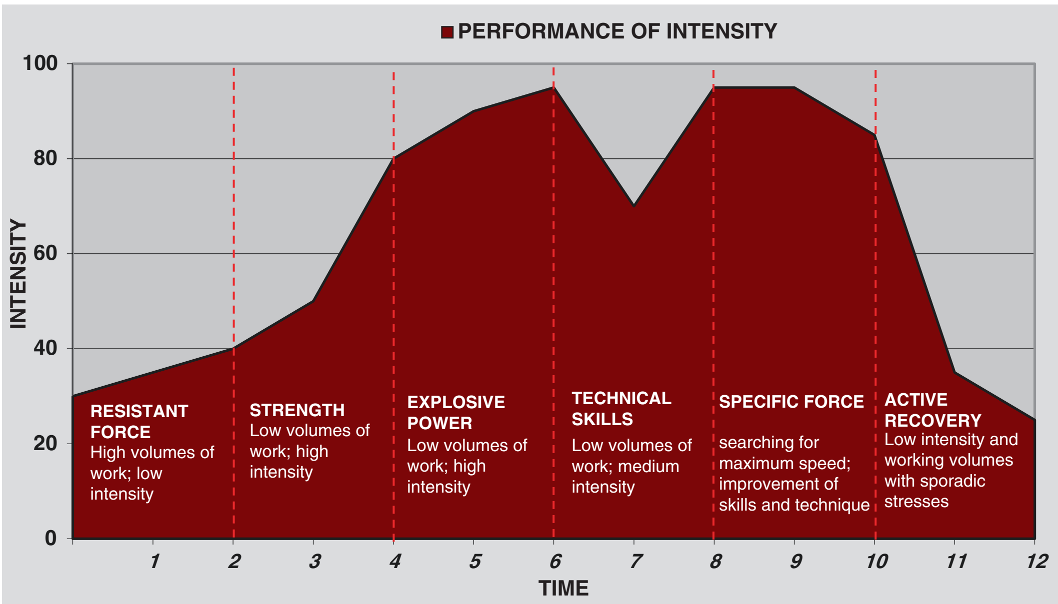

Fig. 13.9 Example of the trend of intensity in a general motor recovery plan

it possesses without fatigue compromising performance. After the sessions of strength, speed, and power, so as not to compromise the effects obtained by conditioning them and to facilitate the transfer of the newly trained skills directly to the athletic gesture, I suggest always to insert a technique and/or skill unit.

The positioning of the resistance is like a jolly, that is, if you want to condition your skills and technique with the highest degree of lucidity, the resistance unit must be inserted after that. However, when the predetermined goal is to train the athlete to maintain a precise degree of skill and technique even with the onset of fatigue, the resistance unit is first performed.

Mental training should preferably be placed on weekends to create the right propensity for performance in the day usually devoted to competitions.

The subdivision of the training units is calibrated depending on the physical ability you want to prefer at that sporting moment (endurance, strength, speed, explosivity, skill, mobility, technique, mental).

As the above model has shown, even when it has been decided to give maximum attention to a specific quality, the others are never excluded but only reduced. In doing so, it takes advantage of the mutual strengthening effect of different qualities (e.g., strength reinforcement helps to increase the speed; the increase in resistance maintains the correct technique over time; the increase in mobility improves both skills and speed, etc.).

After the athlete has gained a good degree of strength (adaptation phase) with the first functional cycle (short-term objective), one must progress by conditioning the strength, power, technical skills, and specific strength (Fig. 13.9).

Conclusions

Taking back an athlete who practices combat sports after a trauma, to maximum performance, is not an easy task. I tried to emphasize all the most important variables that come into play during motor recovery, but remember that the unforeseen are always around the corner. Therefore, you should have to be ready to adopt strategies to solve the problem.

To do this, you must always listen to the athlete and collaborate continuously with all the figures involved in the world of competition. In my opinion, for a good result of healing and returning to maximum performance, a good synergy between surgeon, physiotherapist, athlete, technical mental coaching, and nutritionist is needed.

Finally, remember to always listen to the athlete's impressions, taking into account even the smallest detail. "It's better to overestimate instead to underestimate ...". In this way, you will always be ready for any event.

Further Reading

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14 The Psychology of Sport Injury Rehabilitation

Mario Ganz

14.1 Sport Injury in Psychology

Serious athletes come in two varieties: those who have been injured, and those who have not been injured yet. Brown [1]

14.1.1 Introduction

In the contemporary community, sport has become a very important way for people to express themselves, to acquire self-knowledge, and to create relationships and social links, gaining multiple proficiencies in the process.

The European Council has defined sport as "all forms of physical activity which, through casual or organized participation, aim at expressing or improving physical fitness and mental well-being, forming social relationships or obtaining results in competition at all levels."

Sport therefore becomes, in its highest expression, both an individual and social chance for psychological, physical, economic, and moral improvement, creating—in some cases—emotional and life experiences that are unique for all of those parts involved, independently from the agonistic level.

Although athletes and sportsmen try to avoid accidents and injuries, in the long term they are likely to happen. At the present moment the literature has demonstrated that medical science is capable—in most cases—of restoring the athlete to his preinjury level or, in some cases, enabling him to attain an even higher level.

In the event that the aforesaid scenario does not eventuate—in the absence of a clear medical explanation—the medical community agrees on the fact that psychological factors can intervene, preventing the athlete from returning to his optimal level.

Drawing from the existing sport injury literature, it is apparent that both physical and psychological factors can have a significant impact on sport injury susceptibility, injury occurrence, cognitive appraisals of injury, emotional and behavioral responses to injury, overall injury recovery outcomes, and the return to sport. It has also been suggested that the use of psychological interventions can be beneficial in the context of sport injuries as they have the potential to:

- Reduce athletes' injury susceptibility
- Facilitate injury recovery

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- Provide a sense of control over the rehabilitation process, subsequently enhancing motivation and rehabilitation adherence
- Increase communication between the athlete and the medical professional working with him

These can help injured athletes to attain greater understanding of the injury process and possible recovery outcomes. Greater understanding of the injury can also affect treatment compliance, which is also believed to have an effect on athletes' coping skills and injury recovery. Moreover, athletes who engage in psychological interventions that enable them to perceive themselves as active agents in their recovery are more likely to have better physical recovery outcomes.

14.1.2 Psychological Antecedents of Sport Injury

Sport-related injuries are a significant public health concern for physically active individuals. As a result, it is not surprising that sport injury surveillance and prevention efforts have included deployment of national and organizational monitoring systems, safer equipment and playing environments, and policies.

Yet, among those widespread changes, psychological factors are rarely considered within comprehensive sport injury prevention recommendations.

Certainly, in fighting or impact sports, the theme of injuries, pain, and accidents is more widely perceived—and even taken up—as a potential matter of fact; fighting sport athletes realize that it is possible to get injured or injure, and to suffer or cause accidents, even during daily training sessions—sparring being an example.

We first address the antecedent theme in a general sense by using the Andersen and Williams [2] stress and injury model.

According to this model, the likelihood of injury will be influenced by an athlete's perception of stress in a given situation. The model presumes that an athlete's personality, stress history, and coping resources all influence the athlete's cognitive appraisal of stress, which may either intensify or mitigate his response to stress within the athletic environment and enhance his risk of sustaining injury. In stressful athletic situations, individuals with certain personality characteristics (such as trait anxiety), high levels of stress, and few coping resources (lack of social support, for example) appraise the situation as potentially threatening and perceive an inability to manage demands. As a result, those athletes will likely exhibit heightened stress reactivity, reflected by poor physiological functioning (increased muscle tension, for example) and/or attention functioning (peripheral narrowing or increased distractibility, for example), which, in turn, places them at greater risk of incurring athletic injury.

According to the stress and injury model, stress responses may involve disruptions in athletes' cognitive, attentional, and physiological functioning.

There are some works that have identified stress responses by measuring athletes' perceptions of their stress vulnerability, their reaction time, and their attention/visual indexes.

Some of these elements are related to stress signs and responses that significantly ease the risk factors for the injury.

It is essential for medical professionals working with athletes to consider providing adequate education on these themes in order to increase awareness of the protection factors to be applied (for example, healthy nutrition, adequate rest, prevention of overtraining, and recommendation of relaxation training). The purposes are to increase performance, reduce stress agents (which cause pulled muscles and injuries), and prevent unconscious responses.

At high levels, after all, sport is always hypertraining and, so to speak, "peculiar": the professional sportsman puts his body (organism)—to the extent that it is trained or genetically equipped—under conditions of pressure.

Which are the antecedents proposed by the model? There are three of them: personality factors, stress history, and coping resources.

The body of literature has generally supported all three injury antecedent areas as significant predictors of injury, albeit with incredible variance in methodology. Psychological factors receiving the most attention that have been consistently tied to injury risk include competitive trait or sport anxiety and life event stress, both of which result in vulnerability to injury. Additionally, the presence of coping resources appears to protect against injury risk, whereas the lack of them heightens the risk.

14.1.2.1 Personality Factors

In their original model, Andersen and Williams assumed that certain positive personality traits (such as hardiness) enabled athletes to view athletic situations as challenging rather than threatening, resulting in a lower stress response and subsequently lower injury risk.

Generally speaking, the typical personality factors that in this context are more considered are trait anxiety, the locus of control, and the mental and emotional states.

Anxiety, especially competitive anxiety, is the object of various works. We deem particularly adequate the definition provided by Martens et al., which speaks of competitive anxiety as an athlete's tendency to perceive competitive situation as threatening and to respond to these situations with heightened anxiety or feelings of fear and tension.

Those athletes who significantly suffer competitive anxiety show concentration difficulty, negative thoughts, incapacity to regularly nourish themselves during the days before the contest or the match, and sleep disorders the night before the performance, in addition to numerous symptoms as well as imbalances in some physiological parameters. The research suggests a significant correlation with injuries, in addition to lower performance.

"Locus of control" refers to an athlete's perception of who or what is responsible for what happens to them. Some studies have found relationships indicating that a higher internal locus of control score is associated with a greater number of injuries.

Mental and emotional states: Numerous states of mind and emotional states are related to injury-predictive factors; among these are anxiety and agitation, anger, and negative and depressed moods. In particular, anger and hostility feelings toward oneself and other people are apparently the most important risk factors.

It is necessary for sport medical professionals to take into consideration these general indications when they begin to work with an athlete; they need to understand them from that person's point of view.

14.1.2.2 Stress History

Most probably, stress is the factor that is most related—partly because it is taken more into consideration—to the possibility of injury. It is a common experience anyway—even in our daily life—that during stressful periods more muscle strains, minor home or car accidents, and minor injuries, even in simple actions, are more likely to happen. We may cite three key elements: major life events, daily hassles, and prior injury history.

To minimize the possible risk of injury, athletes, coaches, and sport medicine professionals should be particularly sensitive to increased stress levels, including both major and minor events, and regardless of whether the events are perceived to be positive or negative.

Specific ways to monitor stress include the use of a stress journal or a log, or simply frequent interactions and open communications between athletes and their support staff network.

14.1.2.3 Coping Resources

Coping resources reflect internal factors such as general coping behaviors (for example, self-care, sleep, and nutrition) and psychological coping or mental skills (for example, management of thoughts, energy/emotions, and attention/focus), as well as external factors (such as social support). Simply stated, coping resources include an athletes' personal and environmental strengths and vulnerabilities in managing the demands of stress.

Further, Smith et al. found that athletes who were most vulnerable to stress-mediated injury were those who were low in both coping skills and social support, reflecting a conjunctive moderating effect. Interestingly, a few studies also demonstrated that among athletes with low stress, those with high social support were likely to be injured, suggesting that social support may enable athletes to take risks and/or achieve elevated arousal, which in turn may increase vulnerability to injury. Overall the evidence suggests that coping resources may serve to protect some athletes from injury, while for others, they may result in increased vulnerability to injury [3].

The limited findings on coping resources reinforce the need for sport medicine professionals to get to know individual athletes to better understand their own unique coping resources within their own sporting environment. Sport medical professionals should have an awareness of any athletes who may not have a supportive network around them or who appear to be coping with the demands of personal and athletic life in relative isolation.

14.2 Psychological Intervention in Sport Injury Rehabilitation

The scope of intervention in sport psychology—as well as in clinical psychology—with respect to trauma and injury recovery is wide. In the next section we will attempt to provide an overview of the main methods in use.

14.2.1 Mental Training

Mental training is an efficient set of strategies aimed at helping athletes to acquire and implement the mental and physical abilities needed for performance improvement during competition or even during recovery from it.

The mental training program basic abilities are:

- Relaxation (distension technique)
- Ability to encompass a goal (goal setting)
- Imagination and visualization (imagery)
- Management of psychological/mental energy (arousal management or activation)
- Attention and concentration abilities (internal–external focus)
- Handling of anxious and stressing situations (stressor identification)

During knowledge acquisition and implementation of the aforesaid abilities, the following also have to be considered:

- The coach figure
- Test results
- Motivation and self-esteem
- Self-talk (internal dialogue)
- Individual thoughts and perceptions
- Distraction factors both before and after competition
- Communication
- Injury
- Leadership
- Emotions

Next we will examine some main points concerning mental training and some clinical interventions such as hypnosis and eye movement desensitization and reprocessing (EMDR) therapy for recovery from injuries or from sport traumas.

14.2.2 Goal Setting

Goal setting is one of the key goals of mental preparation in the sport environment, although it is also a natural part of many other extra-sport environments such as school or work.

Proper understanding of the goal a person wants to achieve, in how long a time, and by which strategy, significantly increases the chances of success and allows the person to have a true picture of what could become a project with certain features; thus the aim becomes the truth.

It is important to clarify our choices and the decision making that goes along with them. Sometimes we have the right motivation input for working on a goal but we misjudge our method or we get the timing wrong time; sometimes we are deceived to try and achieve what we want too soon and we vanquish our efforts, and our energies then end up in a distrust spiral.

Focusing our attention on a goal allows us to acquire the necessary competencies for the achievement of our objective, thus increasing our own feeling of self-sufficiency and our self-esteem.

Objectives that are difficult but achievable lead us to produce more effort, and their specificity addresses our efforts in a proper way.

In this way we create a cyclical relationship between cognitive and motivational processes.

The direct objectives of a specific task are aimed at increasing motivation to stimulate the creation of cognitive strategies for trying to achieve the goal; the solution, once found, supports the effort and perseverance.

Upon an increase in the task, strategies are identified after certain reflection, thus activating creativity as well as the mechanism of researching useful information; the cognitive processes became less automatic and more "expensive" from the energetic perspective.

The choice of target is a function with many factors:

- The task's importance
- The thought of positive or negative consequences
- The concern of other people (fellow sportsmen, staff, coach, family, friends)
- The experiences personally lived
- The expectations of success
- The capacity to keep the situation under control
- Self-efficacy and self-esteem
- The ability to face and solve problems
- Self-confidence

The sport psychologist uses a special working grid (scheme) for both measurement and recording of a log book, which is useful during the recovery phase from an accident.

Self-efficacy is a basis for goal achievement.

Self-efficacy is an essential psychological factor for goal setting. It leads us to reflect on the capacity to believe in our resources and our means of achieving the goal, and on the development of such a capacity for sport events.

Athletes who believe in themselves and in their capacity to cope with hardship have more chances of success than those who—sometimes or often—doubt their potential. Moreover, athletes who have confidence will strive more in the face of obstacles or special tension moments and will keep alive in themselves the idea of being able to achieve their goal as previously foreseen. They also will not have an attitude of renunciation in the face of a slightly or moderately compromised sport situation.

On the other hand, those athletes who show low self-efficacy fear defeat and react badly to error as they do not forgive themselves and are no longer mentally involved in the game, which—relentlessly—goes on.

They start to see themselves as losers and hence really do become losers.

To provide a better example of the negative spiral related to low self-efficacy, we start with an athlete who has negative expectations of a certain contest.

He actually feels that he is not trained enough or even not capable enough to face the event: the distrust in his capability—fomented by these negative thoughts—increases the actual likelihood of defeat.

This competition defeat will lead the athlete to the insecurity threshold, which—in turn—will trigger the aforementioned thought mechanism. He will think—and become even more convinced—that he is not able to achieve the goal at hand.

14.2.3 Imagery

Imagery techniques—which have been confirmed by tests measuring cerebral activation and by the mirror neuron theory—allow the athlete, even if he is immobilized or not capable of training himself, to visualize actions, behaviors, and scenarios.

Let us start with a reminder that visualization is not mere remembrance of objects or facts that have already occurred; we may instead work on possible future events or only conceivable events; I may be working on an error or my motor movement, but I may also visualize a final triumph of mine, including its minor details, in a foot race that I will do the following week. This can be done even though I will be not the favorite competitor but only one of the possible winners among a shortlist of five athletes.

The view may be:

- Reproductive when it refers to a past act
- Creative when it refers to the future
- Emotional when it brings in itself an emotional trail that is linked to the event
- Programmatic when it follows a specific and detailed motion program
- Training when its purpose is that of training the gesture through mental repetition
- Regulating when its purpose is that of correcting a motional gesture

The view becomes—on the basis of many works—particularly efficient if it is coupled with training; in fact, it does not replace physical activity but completes it, becoming then a valuable support to the work of the trainer/teacher.

The most accredited assumptions taken for explaining the view process are psychological–neuromuscular theory, symbolic learning theory, and bioinformational theory.

14.2.3.1 Psychological–Neuromuscular Theory

According to this theory, gestures that are made while we are imagining produce unconscious neuromyographic activity, which is recordable through an instrument called an electromyograph, used for quantifying muscular activity during biofeedback proceedings, as an example. This instrument is also used when a polygraph test [so-called questioning using a lie detector] is carried out.

Psycho–neuromuscular theory presumes that the motion sequences that are imaged through the view process produce very small nerve stimulations of the muscles involved in the activity we are thinking of and also produce other kinds of responses (such as emotional responses related to both the sympathetic and parasympathetic systems) that are similar to those that occur during practical execution.

According to some authors, these minor pulses facilitate the motion memorization process, causing then a more than favorable hook-up to the motion gesture as well as to future events. From this research comes the concept that to really make a movement—or merely image it—will trigger the same nervous paths that convey the message to the muscular system. The views then will stimulate the nervous paths that are involved in the motion pulse. In this way we understand that—according to the previously discussed theory—the view is considered as an actual simulation of the real behavior, having effective consequences for the muscle system.

14.2.3.2 Symbolic Learning Theory

According to this second theory, the view viewing ability is useful for strengthening the movement's symbolic and cognitive perspective more than to get the muscle system involved. The activity carried out through cognitive functions (thoughts, reasoning, intentions, and so on) is advantageous in terms of the view more than mere motor activity. This theory is thus in conflict with the previously discussed psycho-neuromotional one. What is learned through repetition of the perceptive–motional tasks is the performance's cognitive elements.

By the way, this theory highlights the importance of the motional input (as the motivation comes by cognitive processes) of the subject and his influence on the physical motion. Apparently the central nervous system (which governs the cognitive process) is responsible for the positive effects of the view effects, more than the peripheral nervous mechanism.

14.2.3.3 Bioinformational Theory

This theory has its basis in the work carried out by Lang and assumes that the emotions linked to the views involve a concepts' structured net encoded and stored in long-term memory, containing information about the features of the imaged situation, as well as the physiological and behavioral output.

Basically, the athlete has in his memory some output models that lead to an effective behavior; the subject's specific experience level concerning the motion gesture, the emotion, and, in general, the event's background establish changes that are measurable in terms of psychophysiological variables.

This means that we visualize what we already know and is already in our memory—also in the case of future or hypothetical events—and that these views may determine changes that are recordable in the subject's motional activity while he imagines the event.

Everything Is More Difficult Concerning an Injury

The injured athlete may have different kinds of problems regarding both relaxation and visualization of pain, stress, uselessness, and so on. It is important to remember that in rehabilitation and injury psychology, views designed to overcome and elaborate what happened are part of the therapy. To do that a specific competency is needed.

14.2.4 Self-Talk

Regarding the term "self-talk" we mean the mental mechanism allowing a subject to silently speak to himself—so-called internal dialogue.

The thoughts that peek out often automatically are able to condition performance both positively and negatively; it is therefore our task to individuate and transform those thoughts that inhibit the athlete's performance.

Negative thoughts are those that could be described as dysfunctional or even not suitable for the objective's pursuit; they reduce the athlete's attention threshold, may cause an alteration in his mood status, and may also provoke a slightly confused status on what has to be done.

Some expressions are therefore to be individuated, and they are useful because they may be installed through EMDR methods (Shapiro).

14.2.5 Relaxation Techniques

Relaxation can be defined as a temporary withdrawal from everyday activity, aimed at moderating the function of the sympathetic nervous system, which is usually activated under stress. When relaxed, individuals typically exhibit normal blood pressure and decreases in their oxygen consumption, respiratory rate, heart rate, and muscle tension.

It has been argued that relaxation techniques should form an integral part of the rehabilitation process. Useful techniques are:

- Progressive muscular relaxation
- Meditation/yoga/mindfulness
- Breathing control techniques
- Autogenic training

Personally speaking, I would add to the above list hypnosis induction techniques, firstly under direction and secondly carried out by the athlete autonomously (self-hypnosis; see Regaldo-Vercelli).

Relaxation techniques are useful during injury rehabilitation for two primary reasons: firstly to alleviate, control, and assist athletes in coping with pain; and secondly to reduce symptoms of stress and anxiety. Use of relaxation techniques can also help to focus the athlete's attention, enhance confidence, and aid healing, as well as providing the athlete with a sense of control over his rehabilitation.

14.2.6 Hypnosis and Eye Movement Desensitization and Reprocessing

Hypnosis can help competitive athletes to deal with pain and injuries. Learning to dissociate themselves from the pain can help them to better cope with it and perform in spite of it. Hypnosis can also help athletes to recover more quickly from a sports injury. By accelerating the recovery time the athlete can return to practice and competition more quickly, which can be very important for athletes competing at the highest levels.

"Flow" is a concept first identified in 1975 by Csiszentmihalyi and is defined as the mental state of operation in which the person is fully immersed in what he or she is doing, characterized by a feeling of energized focus, full involvement, and success in the process of the activity.

In some ways, flow is similar to hypnosis in that both change the way the athlete thinks, processes information, and dissociates from the task (acts without thinking).

By using hypnotic regression, sport psychologists believe they can bring an athlete back to peak performance and have them describe their feelings at the time.

Once the feelings, moods, and emotions from that peak performance are identified, an athlete has a better understanding about when and why they perform well.

These zones of optimal functioning, as Hanin describes them, are very specific to the athlete and thus must be determined individually.

There are well-documented cases in which hypnosis has been effective in the reduction of an athlete's pain.

In a study in 1964, Ryde used hypnosis to treat injuries including tennis elbow, shin splints, Achilles tendon sprains, and others—all successfully. It is important to note, though, that there was no comparison with a control group treated with a placebo.

Other studies have shown that pain can be effectively treated by morphine or a placebo in anxious patients.

Further help comes from EMDR therapy—an integrative psychotherapy approach that has been extensively researched and proved effective for the treatment of trauma. EMDR is a set of standardized protocols that incorporates elements from many different treatment approaches.

Scientific research has established EMDR as effective for posttraumatic stress, and in 2013 the World Health Organization established EMDR as an evidence-based therapy, considering it as an elective therapy for psychological trauma.

EMDR seems to have a direct effect on the way the brain processes information. Normal information processing is resumed; thus, following a successful EMDR session, a person no longer relives the images, sounds, and feelings when the event is brought to mind. He still remembers what happened, but it is less upsetting. Many types of therapy have similar goals. However, EMDR appears to be similar to what occurs naturally during dreaming or rapid eye movement (REM) sleep. Therefore, EMDR can be thought of as a physiologically based therapy that helps a person see disturbing material in a new and less distressing way.

14.2.7 Social Support

Specifically relating to the injury context, social support has been defined as "a form of interpersonal connectedness which encourages the constructive expression of feelings, provides reassurances in times of doubt, and leads to improved communication and understanding" (Heil 1993). Social support is a multifaceted process in which an athlete is aided by the existence of a caring and supportive network (family, friends, partners, sport team members, and medical staff), as well as by their perception of other people's availability to provide helps in times of need and by actual receipt of support. It has been argued that the primary purpose of social support during injury rehabilitation is to afford an athlete a sense of belonging and assurance, which might help to convey in real terms that they are not isolated in their experience of injury and instead have a support network readily available to assist them in the rehabilitation process.

The presence of social support is linked to beneficial health outcomes. For example, social support might "buffer" injured athletes from potentially harmful effects of stress, directly influence appraisal of their injury in a helpful manner, and aid the management of emotional and behavioral responses during the rehabilitation process.

14.3 Psychological Rehabilitation: Influence of the Sport Medicine Team

Injured athletes often come into the rehabilitation process as they hope to regain—as promptly as possible—both the physical and technical levels of proficiency they had achieved before the accident. This sometimes conceals their fear about returning to their sporting life (in cases of severe trauma they may suffer posttraumatic stress disturbance) or even their impatience to demonstrate that their situation is under control by minimizing the repercussions produced by the accident.

It is therefore necessary to bear in mind both the physical and psychological perspectives regarding the course by offering the athlete/patient the opportunity to take charge both globally and holistically.

The process of rehabilitation, at its best, will involve a number of people working closely together for the benefit of the athlete, with the aim of ensuring a full and safe return to their pre-injury level—or even a higher level—of health, well-being, and performance. The care provided should entail the involvement of relevant sport medicine professionals, as well as the use of sport psychologists.

14.3.1 Primary and Secondary Rehabilitation Teams

Arvinen-Barrow pays close attention to a multidisciplinary approach to rehabilitation by making a distinction between primary and secondary terms, which are—as we will consider later on—basic for offering a complete path to rehabilitation [a treatment program] that takes into consideration the various steps and the sportsman's individual needs.

When considering rehabilitation teams, the primary rehabilitation team often consists of those sport medicine professionals who will closely work with the injured athlete from injury occurrence though the entire rehabilitation process until their successful return to the field of play or the ring. Typically, these would be the primary treatment providers (the physiotherapist, trainers, and the physician/orthopedic surgeon).

They are in an ideal position to inform, educate, and assist with both the psychological and physical processes of injury. Indeed, it appears that members of the sport medicine team are the first to attend to injured athletes' needs and are often available immediately after the injury occurs.

The secondary rehabilitation team should ideally consist of a range of sport medicine and health professionals, as well as related others with whom injured athletes will have varying degrees of interaction throughout the course of their rehabilitation. Members of this team often contribute to the injured athlete's rehabilitation experience in different ways, not only physical ones. The individuals that should make up this team include, but are not limited to, sport and clinical psychologists, nutritionists, sport physiologists, strength and conditioning coaches, nutritionists, massage therapists, partners, and teammates.

It is evident how essential it is that these figures are involved and are able to cover part of the injured athlete's needs [4].

But to do that it is appropriate to study the different relationships between the professional figures: the ideal would be to set up a team where information and communications are circular, and where team members may know each other, underlining their different competencies and the chance to become a multidisciplinary team [unit] operating on and with the athlete. In addition to the evident benefit of working in a team —"putting the pieces together"—we ensure that the athlete feels looked after and understands that the rehabilitation path is drawn up, accurate, and coordinated. Surely the primary rehabilitation team has the central role in creating the starting conditions of a prompt and effective medical staff.

14.4 Conclusion: Role of Sport Medical Staff

As we have said, given the importance of addressing both the physical and psychological aspects of injury rehabilitation, the primary team takes a leading role in the incorporation of psychological components. "The mind is crucial in the sport"—this sentence is often repeat by the combat sport's athletes, expressing in this way a good measure of truth, and even more so if we consider mental involvement during a period of psychophysical difficulties.

As the sport medicine professional's job often involves working with injured athletes on a one-to-one basis, the likelihood of effective communication, building of trust, and rapport with the athletes will be increased, subsequently having the potential to facilitate greater levels of rehabilitation adherence and treatment compliance, to increase motivation, and to have a positive impact on the overall recovery process, as some research has demonstrated [5].

Kolt [6] writes that sport medicine professionals are best suited to providing psychological assistance for injured athletes for three reasons:

1. Psychological issues, which often present themselves as a result of injury, are often discussed in conjunction with physical aspects of rehabilitation.
2. The treatment and rehabilitation of injured athletes typically involves touch, which can often facilitate athletes' opening up to their sport medicine professionals about psychological issues in their recovery.
3. Existing studies suggest that athletes themselves feel that sport medicine professionals are in an ideal situation to address psychological aspects (Larson 1996).

So, sport medicine professionals should:

- Know their role in cultivating a multidisciplinary approach to rehabilitation
- Recognize the importance of significant others in ensuring an holistic approach to recovery
- Think about ways in which psychology can be integrated into rehabilitation as part of the process rather than as an addition to it
- Continue to seek out additional training in the psychological area
- Know their professional boundaries and competencies
- Know when to refer athletes and to whom
- Have access to a network of other sport medicine and allied health professionals and related others

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15 The Management of Carpal Scaphoid Fractures and Nonunions and the Role of Capacitive Systems

Pier Paolo Borelli

15.1 Introduction

Fracture and nonunion of the carpal scaphoid remain a difficult problem to face, regardless the activities of the patients.

Generally the problem is more difficult to deal with in athletes for their needing of a quick return to sport activities.

But fracture and nonunion of the carpal scaphoid in combat sports are to be considered a devastating injury, and the establishment of a nonunion has the potential of ending the athlete's career [1]. Therefore in combat sports, it is essential that these injuries be diagnosed and treated quickly and effectively to minimize loss of training time and competitive opportunity.

Borelli: as the chapter is based on a previous Italian publication that was successively translated and enhanced, we should insert this special note:
Partially based on: P.P. Borelli (2007) Fratture e pseudoartrosi dello scafoide carpale. In Landi, Catalano, Luchetti (eds) Trattato di chirurgia della mano, 2007, Verduci Editore, p 256-290; P.P. Borelli (2015) Fixing the carpal scaphoid nonunion, Archivio di Ortopedia e Reumatologia 1 Vol. 126 - 1-3, 2015, ASST G.Pini-CTO.

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15.2 Scaphoid Fracture Management Overview

15.2.1 Undisplaced Fractures

Undisplaced waist scaphoid fractures are common in active youngsters and adults during sporting activity, and patients should make an informed choice between immobilization in a below-elbow plaster or splint, even with the thumb free [2], and screw fixation, with percutaneous volar or dorsal techniques whenever possible. If casted patients are advised that at 6 weeks, radiographs and/or CT scan may show no evidence of union, and internal fixation may then be indicated.

Proximal pole fractures, even if undisplaced, may not unite in a cast in higher percentage than waist fractures. In young active patients, the trend is to promote their fixation from the dorsum as a primary indication, even considering that the evidence of a real benefit is weak [3]. So every effort to improve the prognosis should be done, such as stimulating union with capacitive system [4], regardless its location, in a patient made adequately well informed as consent and that can afford a possible long healing time, such as students and young athletes not agonist, but avoiding the risks of surgical treatment. In this regard, the capacitive systems, combined with the last generation splints, may play a very important role [4].

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Volar percutaneous fixation, regardless its growing popularity, may be technically challenging [5–7]: central screw placement may not be easy for the presence of the trapezium and because the fracture location and orientation is not always biomechanically adequate for a retrograde screw introduction [7, 8].

Regarding the trapezium prominence, some suggestions have been proposed, such as positioning the wrist in extension and ulnar deviation [9, 10], removing a volar portion of the trapezium [6], a dorsally displacement of the trapezium during fixation [10], introducing the screw through the trapezium [8, 11, 12] and introducing the screw through the tuberosity without violating the scaphotrapezial joint [13, 14].

Regarding fracture location and orientation, suggestions have been proposed not only in transverse waist fracture [15] but above all in oblique waist fracture where proper positioning of the screw may be particularly demanding [5, 16–18] with the risk of provoking an unwanted fracture displacement on coronal and sagittal plane [7, 19].

In practice the literature reports several studies stimulated by the biomechanical aspects related to the volar percutaneous fixation, all aimed at answering a question: is it always possible to achieve adequate positioning of the screw and therefore a stable fixation with a volar percutaneous fixation?

If the presence of the trapezium can be overcome by using specific instruments to dorsally displace the trapezium during fixation [19], fracture location and orientation is a more difficult problem to face.

Screw fixation of the scaphoid cannot be performed in a uniform way and above all cannot be performed considering only the coronal plane. Fracture location and orientation evaluated on both coronal and sagittal plane should determine which approach allows the best fixation [4, 19].

In most waist scaphoid fractures analysed in the X-ray coronal plane, a screw introduced along the longitudinal axis is perpendicular to a transverse fracture plane and is biomechanically effective [14]; in an horizontal-oblique or in a vertical-oblique fracture, the screw's introduction line has to be adapted and may not correspond to the longitudinal axis of the scaphoid. But in all possible cases of coronal orientation of the fracture's line, the sagittal plane orientation of the fracture's line has to be concurrently analysed in order to consider as effective the scaphoid screw fixation [4, 8, 19].

Preoperative informations on sagittal plane fracture orientation coming from CT three-dimensional analysis [11, 20, 21] may be important in the surgical strategy of a volar retrograde fixation of the scaphoid with a headless screw in order to choose the best approach among a true percutaneous fixation, a mini-open approach to the tuberosity and a standard mini-invasive open approach [19].

15.2.2 Displaced Fractures

Displaced unstable waist scaphoid fractures always require screw fixation. The meaning of displaced or unstable fracture is still controversial. CT is superior to radiography in assessing the type of displacement in waist fractures, but arthroscopy is even more accurate [22]. Usually a gap larger than 1 mm means a displaced fracture that needs to be fixed, but any complete fracture of the waist has to be considered as unstable and fixed [23].

Reduction can be achieved by an open approach and confirmed anyway using image intensification or by a percutaneous approach and by manipulation of the proximal and distal fragments with two separate K wires and confirmed with arthroscopy [24, 25]. Arthroscopy allows visualizing also an eventual concomitant ligament injury [26].

In waist fractures, screw fixation is achieved through a volar or dorsal approach, in relation to the location and direction of the fracture line.

For proximal pole fractures, dorsal fixation with a headless screw appropriate for the small size of the proximal fragment is the treatment of choice. The surgical approach includes an open or mini-open dorsal approach or percutaneous technique with or without arthroscopic assistance. [24, 27, 28]. For some authors, the dorsal open approach is superior to dorsal percutaneous approach in avoiding the risk of incorrect positioning of the screw [29, 30]

15.3 Considerations on Scaphoid Fractures and Nonunions in Athletes and Combat Sports

Generally an elite athlete sustains a scaphoid fracture, falling on an outstretched wrist, during a game, and usually complains some wrist pain or a weaker wrist. In baseball, the player is typically out, but in football, hockey and soccer, they often continue to play through the game, depending on their position [31]. After the game, the wrist pain and swelling may become more evident pushing the athlete to seek care, even if sometimes, we know, the clinical symptoms subsides, and a scaphoid fracture is diagnosed later on as a delayed union, nonunion or a SNAC wrist.

Early diagnosis and appropriate treatment provide anyway the best opportunity to heal a scaphoid fracture.

Nowadays the trend is to indicate screw fixation of any type of a complete scaphoid fracture in order to offer the active athlete a quicker return to the rehabilitation and earlier return to sport activity participation and healing [32].

After fixation, athletes are typically placed in a removable thumb spica splint for 10–14 days. Radiographs are repeated at 2 and 6 weeks to detect obliteration of the fracture line and bridging trabecular bone formation.

It is advisable a splint protection of the wrist until a complete scaphoid healing is demonstrated by X-rays or CT scan, before returning to competitive sport activity.

In sports in which the wrist is not involved in precision work, a protective splint may allow an early return to competition.

In all throwing and hand performance sports (volley, basket, rugby), after scaphoid screw fixation, a CT scan is used to assess healing, thus allowing players to return to unprotected play, usually after 4–6 weeks [33–35] or earlier in consideration of player position and ability to play with protection [36].

Combat sports (boxing, kickboxing, Muay Thai, karate, wrestling, taekwondo, judo, Brazilian jiu-jitsu, sambo) were in the past practiced almost exclusively by competitive fighters but are increasingly popular and have become accessible to wider range of practitioners of all ages. Cardio kickboxing classes also have become a popular form of exercise to enhance fitness, and hand and wrist injury from kickboxing exercise is becoming more and more frequent.

In particular in boxing, the athlete lands his blows primarily with the heads of the 2nd and 3rd metacarpals, and the force is transmitted along the shafts and through the capitate, scaphoid and lunate to the forearm. This makes the scaphoid bone and scapholunate ligament particularly susceptible to injury.

In combat sports, regardless the displacement of the fracture, the primary indication is screw fixation for an early return to sport activity, both training and agonistic activity.

But in combat sports, we have also to consider the biomechanical influence of headless screws on subsequent fracture of the healed scaphoid that has been reported in competitive athletes with repeat traumatic load application [37].

So the potential for this complication in young and active combat sports athletes warrants discussion with patients and should be included in the informed consent [38].

External bone stimulation is often added in the elite athlete to the initial surgical treatment for the scaphoid fractures to augment the healing process, above all in scaphoid nonunions [39, 40].

15.3.1 Occult Fractures

Patients who present with snuffbox tenderness after a susceptible mechanism of injury suggestive of a scaphoid fracture but without a clear radiographic evidence remain a perplexing scenario particularly in the athlete. Advanced imaging modalities to improve the detection of an occult fracture have been proposed to avoid unnecessary immobilization of the athlete. Ruling out a scaphoid fracture by CT scan or MRI in the athlete can assure the patient and physician that returning to play is acceptable without increased risk of late scaphoid complications [41]. A quick confirmation of a scaphoid fracture will allow the surgeon to perform an appropriate early surgical treatment.

15.3.2 Incidental Nonunions

A therapeutic dilemma still remains when X-ray reveals an incidental nonunion of variable duration. In fact often an athlete involved in combat sports suffers an injury to the wrist during training or a match and initially does not seek a medical opinion and move on to fight. The pain subsides a little at a time, and his competitive activity may continue without interruption even for years, until the snuffbox pain recurs and a nonunion of the carpal scaphoid becomes apparent on X-rays. It is true that nonunions lead to degenerative changes and eventual wrist disability, but most nonunions remain asymptomatic and do not require treatment, above all if a nonunion has withstanded the stress of combat sports asymptomatically [1]. Surgical treatment should be reserved for symptomatic patients, considering that the athlete may decline "screw fixation" for the desire to quickly return to a competitive activity. A return to "fighting" with no symptoms, completing an agonistic career, in spite of an evolving SNAC wrist, has been published and has to be considered in these particular situations. In practice the forced stop from training and competition due to the surgical treatment proposed, without the guarantee to return to a vigorous level of boxing, is often considered more deleterious to the career than an asymptomatic or even painful nonunion [1].

15.4 Classification of Acute Scaphoid Fractures

Among all classifications proposed in the literature, based on different aspects such as fracture plane orientation [42], fracture displacement and/or instability [43–45] and fracture line location [44, 46], the one with the greatest consensus is the Herbert and Fisher [23] classification combining fracture direction and location, stability and history with the aim to produce a prognostic value. The type A is a stable incomplete waist fracture, the type B1 an horizontal-oblique waist fracture, the type B2 a transverse waist fracture, the type B3 a proximal pole fracture, the type B4 one of the fracture-dislocation patterns, and the type B5 a comminuted fracture. All type B fractures are unstable and "may require surgical treatment" [23].

But the research of an updated classification predicting instability to improve identification of the small subset of scaphoid fractures unlikely to heal conservatively is still in progress [47].

And the clinical relevance might be important even considering the different surgical treatment options, their prognosis or risk of complications [48].

One thing that unites all these classifications is that their graphical representation considers the fracture only in the coronal plane, while, as already stated, from the three-dimensional analysis of Compson and Nakamura studies, we realize that what is transverse in the coronal plane may be horizontal in the sagittal plane, and this seems to occur more frequently in proximal fractures [20, 21].

15.5 "Imaging" a Scaphoid Fracture

Precisely in view of the difficulty in assessing the amount of displacement on plain X-rays, CT has become the gold standard in imaging fractures and nonunions on both planes, coronal and sagittal, along with the true longitudinal axis of the scaphoid [49, 50], and 3D images may be helpful in the decision-making strategy in choosing the most appropriate surgical approach, percutaneous or open, or confirming union [51, 52], even considering in some particular cases MR imaging of some value in diagnosing the presence of an occult fracture [41], in diagnosing a concomitant ligamentous injury [53], in decision-making strategy in some acute fractures [54, 55] and in predicting surgical outcome in nonunions [56], even considering that regarding the effectiveness and the usefulness of unenhanced MRI and gadolinium-enhanced MRI in correlation with the vascular status at surgery is still controversial [57–64].

Cone beam computer tomography (CBCT) [65–67], a new low-dose high-resolution imaging technique of wrist injuries, is now increasingly used in pre-op assessment of scaphoid fractures and nonunion and is replacing the standard CT as the first diagnostic tool in scaphoid pathology. CBCT will be described more in detail in the paragraph devoted to nonunion.

15.6 Surgical Approaches in Acute Scaphoid Fractures

Each complete fracture (all type B of the Herbert classification [23]) has to be considered unstable fractures. At the beginning they may initially appear nondisplaced but, being complete, have to be considered potentially unstable, and they have to be treated with internal fixation to neutralize shearing forces. Anyway in competitive athletes early internal fixation offers the athlete faster healing and earlier return to elite-level competition. However surgery exposes the athlete to a specific complication such as anesthetic risk, wound infections and failed fixation with nonunion or malunion, so in not professional everyday athletes, casting is still considered as an option treatment (short-arm thumb spica cast) [31] even considering its high risk of nonunion [68].

The surgical approaches in acute scaphoid fractures are the following:

- Open volar approach for displaced waist fractures requiring an open reduction maneuvers, even considering that minimal scaphoid displacement can be reduced applying extension and ulnar deviation on the wrist and checked under fluoroscopy [19].
- Volar percutaneous fixation for undisplaced waist or some proximal scaphoid fractures accepting the size of the trailing thread of the screw, even considering that passing the K wire percutaneously offers no advantage compared with a small longitudinal zigzag or transverse incision down to the tuberosity of the scaphoid. Adequate screw placement from a true volar percutaneous approach may have been described as demanding. Holding the wrist in extension and ulnar deviation with traction through the thumb mitigates most of the drawbacks of the volar approach [7, 19, 69]. Specific fluoroscopic views help to confirm optimal guide wire placement. Preventing drill or screw penetration of the proximal cortex is mandatory with the help of precise fluoroscopic assessment.
- Open dorsal approach with a limited incision for nondisplaced or minimally displaced proximal pole or even for waist fracture depending on type of displacement and surgeon’s attitude.
- Percutaneous fixation through a dorsal approach for undisplaced fractures, with arthroscopic assistance for determining a perfect anatomic reduction of a proximal pole fracture and assessing eventual associated injuries [25, 26, 70–72] or without arthroscopic assistance, allows a more direct access to the central axis [73–76] and thus a better compression but with the disadvantage to create a hole in the weight-bearing surface of the scaphoid [31]. We have to remember that anatomic structures are at risk of injuries with dorsal percutaneous placement of a headless screw into the scaphoid, and incorrectly placed screw above the subchondral bone is possible [77].

15.7 Author’s Treatment Algorithm in Scaphoid Fractures

Author’s proposed treatment algorithm is designed on the Herbert and Fischer [23] classification.

I manage type B3 fractures (proximal pole) in the same way as B1 (waist horizontal-oblique on the coronal plane) and B2 fractures (transverse waist fracture on the coronal plane), simply because I systematically use CBCT to confirm if they are actually undisplaced on both coronal and sagittal planes, and I give them the chance to heal also with noninvasive treatment, when it is indicated for the age and functional needs of the patient.

15.7.1 Adolescence

By adolescent, we mean a 15- or 16-year-old patient.

Adolescence spans the period from 11/12 years of age to 18, the start of adulthood.

At the age of 15/16, functional needs are usually limited: most subjects of this age are students, and, therefore, for a complete but *undisplaced* type B1, B2, or B3 fracture, noninvasive treatment involving 5-week immobilization with a plaster cast may be indicated and should be extended by a further 3–4 weeks depending on the follow-up X-ray results. Personally, for immobilization, I usually opt for a new-generation modular splint,[1] with the first ray included but with the interphalangeal joint left free. Using a wrist brace allows early application of biophysical stimulation, using the capacitive technique with the adhesive electrodes of the OSTEOBIT® medical device.

If the first treatment phase involves the use of a plaster cast, inductive biophysical stimulation can be applied using the BIOSTIM® medical device, whose applicator does not require direct contact with the skin.

An X-ray study with scaphoid-specific views is usually adequate for evaluating the true "undisplacement" of the fracture. A cone beam CT (high-resolution and low X-ray exposure) allows greater accuracy when studying the fracture on the sagittal plane, in those cases in which there are doubts regarding a possible minimal displacement. It also makes it possible to monitor the evolution of the union process.

Displaced fractures require surgical treatment with a headless compression screw suited to the size of the fragments.

[1]Modular splint: a wrist brace combined with a separated and removable, when no more needed, thumb splint.

15.7.2 Adults

15.7.2.1 Undisplaced Type B1, B2 and B3 Fractures

Again, in adulthood, in the 18–25-year age range, those who are students and do not practice sports on a competitive level also have limited functional needs. A prolonged immobilization period of up to 2 months can therefore be considered appropriate, with a follow-up X-ray or CBCT scan in the middle, especially when a wrist brace is used instead of the conventional, awkward plaster cast. Once again, using a wrist brace allows early application of biophysical stimulation, using the capacitive technique with the adhesive electrodes of the OSTEOBIT® medical device. Noninvasive treatment may also be indicated in non-active adults (e.g. office workers) with undisplaced B1, B2 or B3 fractures, as a first treatment option, using capacitive systems; however, the fracture must be investigated by CT to confirm it is actually undisplaced also on the sagittal plane. In any case, patients must also be informed of the surgery option and related advantages and risks, so that they may have a responsible and active part in the choice. Patients who opt for noninvasive treatment must be informed that they may have to have surgical treatment if, at the first check-up X-ray at 5 weeks (combined with a cone beam CT study for ambiguous cases), the union process is too slow.

I believe that "active youngsters" and "active adults" should be managed in the same way. They have the same functional needs.

Those who work or practice sports on a competitive level or who are particularly active from an athletic point of view have greater functional needs. In combat sports, there is a functional need to counter forces acting directly on the scaphoid bone.

The indication for surgical treatment, in order to achieve early mobilization, to favor rapid union that is more likely than with noninvasive treatment and, above all, to reduce the risk of nonunion, expands to make it the first option treatment in complete, undisplaced B1, B2 and B3 fractures. The need to evaluate the "fracture" in greater detail, however, increases precisely due to the risk of a potential intrinsic instability of the fracture to the maneuvers practiced during screw fixation, especially in type-B1 fractures when the fracture is horizontal on the coronal plane, or in any case if the fracture on the sagittal plane is horizontal and not ideal for retrograde volar screw fixation (see Fig. 15.3 in paragraph “Biomechanical aspects on scaphoid fixation”).

This is why I believe that a CT preoperative assessment, preferably using cone beam technology (CBCT), is essential for identifying the most appropriate strategy: true percutaneous volar fixation or using a mini-open approach to the tuberosity (with arthroscopic assistance, if necessary), minimally invasive open volar fixation (sparing both the RLT and the RSC ligaments or at least the RLT ligament), dorsal fixation with the classic surgical approach, percutaneous dorsal fixation or percutaneous dorsal fixation with arthroscopic assistance. Arthroscopic assistance is suggested not merely to confirm that the reduction is anatomic on all spatial planes but also in order to exclude or check the extent of any associated ligament injuries. There is increasing scientific evidence of ligament lesions associated with undisplaced scaphoid fractures, which, of course, alters the approach to post-operative rehabilitation.

15.7.2.2 Displaced Type B1, B2 and B3 Fractures

If the type B1, B2 or B3 fracture is displaced, even by just 1 mm on the standard X-ray study (in which case CT is always essential), treatment must include reduction maneuvers. Personally, I use a wider surgical access while maintaining a minimally invasive approach, i.e. while sparing the RSC and RLT ligaments or at least always the RLT ligament, when it is possible to perform retrograde volar access and fixation using a headless screw, with differentiated leading threads (long and short thread for each length of the screw), in order to adapt to the size of the proximal fragment. If, on the other hand, the size of the proximal pole and the direction of the fracture on the sagittal plane do not permit retrograde volar screw fixation, a classic dorsal surgical access must be used.

Expert arthroscopists can obtain reduction with external maneuvers using Kirschner wires as a joystick and performing volar or dorsal screw fixation with arthroscopic assistance. A number of papers have been published on this technique, which is, nevertheless, to be considered a niche treatment.

15.7.2.3 B4 Fractures

Type B4 fractures always require invasive treatment. The surgical approach depends on whether the fracture/dislocation is dorsal or volar.

Whatever kind of fixation is performed, it is advisable to consider, from the outset, the use of new-generation capacitive systems combined with a wrist brace using an OSTEOBIT® medical device for a localized action on the fracture site or with a BIOSTIM® medical device for a more widespread action if a plaster cast is used.

15.8 Scaphoid Nonunion Management Overview

Regardless the patient’s activity, the surgical treatment of scaphoid nonunion is a challenge for even the most experienced surgeon. The problem is to make a puzzle with many little problems such as nonunion debridement, preserving the residual blood supply in the proximal fragment, anatomical reduction of two or three (in case of an interpositional corticocancellous graft) fragments, carpal instability (DISI) correction and stable fixation.

Matti-Russe bone graft [42, 78], Fisk-Fernandez bone graft [79–81], various types of vascularized bone graft [82–95] and electrical stimulation [4, 96] have been proposed in the past with sometimes impressive reported union rates, which in most cases reach 100%.

In the last 10 years, minimally invasive surgical approaches moved forward the standards of treatment. Moreover wrist arthroscopy is now proposed in scaphoid nonunions for debridement, bone grafting and internal fixation with the goal of avoiding post-operative morbidity, minimize post-operative stiffness and maximize functional outcome [97]. The bone graft varies from injectable bone graft substitutes [98] to autogenous bone graft, and avascular proximal pole is not an absolute contraindications now for a nonunion arthroscopic treatment [99, 100]. And even a concomitant humpback deformity with dorsal intercalated segmental instability (DISI) may be addressed in the arthroscopic treatment of a scaphoid waist nonunion [101–103].

Wrist arthroscopy, more and more increasingly known, is pushing the wrist surgeon to have a more three-dimensional view of the scaphoid to obtain the most appropriate rigid fixation.

Also the use of biophysical stimulation by means of capacitively coupled electric field (CCEF) is increasingly being associated in conservative and surgical treatment in order to promote the bone healing both in scaphoid fractures and difficult nonunions [4].

15.9 Classification and Surgical Approaches in Scaphoid Nonunion

The well-known and widespread in literature Herbert classification [104] subdivides scaphoid nonunions in D1 (fibrous union), D2 (nonunion with early deformity), D3 (nonunion with advanced deformity) and D4 (nonunion with avascular necrosis of the proximal pole) [26].

In regard to this, I would like to just point out that a suffering blood supply can be an additional anatomical condition in each pattern of nonunion and in each stage, which affects the natural history of nonunion and means a less reliable result of the scaphoid fixation.

It is also important to consider, as already described for acute fractures, where nonunion is located in the scaphoid for its implications on the surgical approach. It is easier to fix the scaphoid with a volar approach when the nonunion is located in the distal or medial third (waist nonunion) than when the nonunion is located more proximal, known as "junctional nonunion", sometimes requiring a limited combined approach [105]. At the level of the proximal pole, a dorsal approach (open or percutaneous) is required.

The standard volar approach has become, over time, more and more a mini-invasive approach. Nowadays, the retrograde volar fixation with a headless screw rarely requires to cut the radiocarpal volar ligaments, the radioscaphocapitate (RSC) and the Radio-luno-triquetral (RLT) ligament, even when you have to fix a proximal pole [7].

Usually in waist nonunion, you can always spare the radioscaphocapitate ligament (RSC), even when using a corticocancellous bone graft. Only in a junctional nonunion, sometimes the RSC ligament has to be cut for a better management of the proximal pole but later easily reconstructed.

Even in carpal scaphoid nonunions, percutaneous fixation, dorsal or volar, with arthroscopic assistance if necessary, has become more and more popular as an alternative to the above-mentioned minimally invasive approaches. Percutaneous fixation is particularly recommended in delayed union or fibrous nonunion [76, 99, 106] with no associated intrascaphoid deformity and when the biological aspect of the proximal pole and of the interposed fibrous tissue doesn't require any debridement or any bone graft. Therefore parameters such as pain and time elapsed from the trauma are good indicators, as well as a careful study of the bone density by standard radiographs or even better by CT or MR images [54, 55].

In particular situations, such as failed fixation and long-standing nonunion, arthroscopy means, first of all, the possibility to verify that no degenerative arthritis is present around the scaphoid. After that, arthroscopic bone grafting can be performed in the presence of a previous internal fixation or in case of a nonunion with a humpback deformity or even with proximal avascular changes [101].

15.10 Biomechanical Aspects on Scaphoid Fixation

15.10.1 Biomechanical Considerations on Headless Scaphoid Screw Fixation

In 1984 the Herbert screw was introduced on the market [23], and the surgical treatment of the carpal scaphoid had an incredible acceleration.

The revolutionary concept was the interfragmentary compression forces produced by differential pitch threads during its insertion.

Thereafter a myriad of headless cannulated screws were introduced on the market, focusing especially on the concept of "compression capacity", thinking it was especially compression to solve the problems.

But in reality the first objective in carpal scaphoid fixation is to achieve a stable fixation in order to start a very early mobilization [107].

Thus some questions arise: do you really need interfragmentary compression? How much compression?

It is definitely true that generally speaking some screws on the market determine a higher compression than the original headless Herbert screw [108–110].

But is it really necessary? All technical tests on polyurethane bone simulator such as sawbone and all the drawings included in the brochures about new-generation cannulated headless screws do not reflect the actual clinical need: the two fragments, or two fragments in case of nonunions requiring a corticospongious (CS) bone graft, are already "facing" one another when the screw is inserted, and we all verified how, sometimes, the corticospongious graft tends to be pushed out when interfragmentary compression is too high.

Also when fixing a fracture, the screw compression capacity can cause unwanted side effects, both in the coronal plane (Fig. 15.2) and in the sagittal plane, and the greater the screw compression capacity the bigger the potential dislocating effect.

At the light of these biomechanical concepts, I prefer to use a "low compression index screw" [7], comparing to the other headless screws on the market, and with the same compression index of the original non-cannulated Herbert screw, taking advantage of its scientific evidence in terms of bone healing [107].

A "low compression index screw" means 0.15 mm trailing at each turn of the screwdriver. When the screw is completely buried beneath the surface of the bone, the four threads of the trailing thread will generate 0.6 mm of advancement on the fracture or nonunion. This guarantees an excellent primary stability. This allows to modulate the interfragmentary compression, for example, making one or two turns more if needed (thus reaching the same compression capacity of the other self-compressing headless screws on the market!), without the risk of producing an unuseful excessive compression on fracture or nonunion when trying to bury the screw beneath the bone.

The screw has other biomechanical features in order to obtain a very stable fixation: such as a truncated conical shape of the trailing thread that keeps the interfragmentary compression achieved during the screwing process.

But I would like to underline how the most important factor to obtain a stable fixation is a proper application of the screw according to spatial orientation of fracture or nonunion.

In fact only ideally the carpal scaphoid should be fixed with a headless cannulated screw positioned along the central axis and in the central of the proximal pole. In clinical practice, the particular anatomical links of the scaphoid may create some difficulties in screw fixation considering that a central placement of a screw may violate the scaphotrapezial joint in case of a volar retrograde fixation approach, regardless of whether it's open or percutaneous fixation. So, to avoid this, looking for an oblique direction on both planes is mandatory, and choosing between open or percutaneous fixation is still controversial.

15.10.2 Percutaneous Fixation: Always Possible?

Surgeons use either dorsal or volar approaches for scaphoid fixation, usually depending on the fracture location and/or personal preference. In the volar approach, open or percutaneous, the most frequent used approach for fractures and nonunions, the trapezium may impede an easy access to the center of the proximal pole so central placement of a cannulated headless screw may be difficult to achieve [8].

A true percutaneous fixation, proposed at the beginning, by Haddad and Goddard in 1998 [9, 10] is not always possible to perform, as underlined by Shin in 2003, just for the problems created by the trapezium and thenar muscles prominence [111].

This is why some authors, in case a percutaneous fixation is indicated, prefer a mini-open approach to the tubercle to avoid the damage of superficial branch of radial artery (SBRA) and to enter deeper into the scaphotrapezial (ST) joint [112, 113]

In respect to this, I think it is important to underline the biomechanical property of the increasingly used percutaneous approach to the scaphoid, compared to an open approach, just because it can limit the surgeon's ability to perform a proper fixation of the proximal fragment.

One of the challenges of orthopedic surgery is the ability to think and operate in three dimensions. Nakamura has shown the usefulness of 3D CT scan to assess the fracture or nonunion site that may appear transverse in the coronal plane but horizontal in the sagittal plane, thus making more difficult a proper retrograde volar screw fixation [21]. Compson, in its three-dimensional analysis of patterns, demonstrated that it is difficult to evaluate scaphoid fractures and nonunions orientation in the sagittal plane from standard radiographs. Compson also demonstrates the variable scaphoid morphology both in the coronal plane and in the sagittal plane [21, 114, 115].

In fact, in my clinical experience, sometimes scaphoid fixation may be more difficult just for the scaphoid morphology and not only for the spatial orientation and location of nonunion (Fig. 15.1).

Another consideration can be done on these examples. (a) Coronal X-ray may reveal an undisplaced fracture. Only CT sagittal view may demonstrate a dorsal gap and the fracture spatial orientation. From the same point of screw introduction, not violating the ST joint, a more oblique insertion, even with a percutaneous technique, is possible and biomechanically more appropriate, suggesting that CT informations on the sagittal plane are important for the surgical strategy.

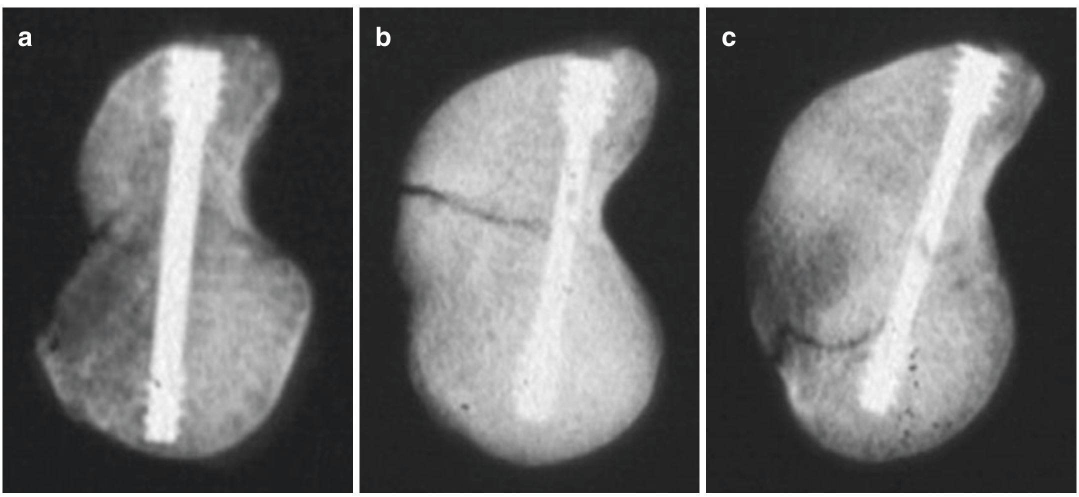


Fig. 15.1 Specimen's scaphoid. Fixation of the fracture, caused in that predetermined sagittal plane, has been performed before scaphoid removal, so respecting and not violating the anatomical links around the distal scaphoid. If we consider, as a point of screw insertion on the tuberosity, the anterior limit of the ST joint articular cartilage, you notice how in some carpal scaphoids (**a**) it is easier to insert a screw with a line of insertion matching the anatomical long axis in the sagittal plane. Besides this morphological aspect, it is evident that also the variable spatial orientation of fractures or nonunions in the sagittal plane affects the biomechanical aspect of fixation: in some cases (**b**), from the same point of introduction, the line of screw insertion can be adapted to a large extent to the spatial orientation of fractures or nonunions, in other cases (**c**) only slightly. And the clinical implications are obvious: percutaneous fixation can be easily performed in transverse waist fractures (**b**) or more difficult to perform in horizontal sagittal fractures (**c**), because the presence of the trapezium inevitably determines a screw oblique introduction. An open approach to the tuberosity [112] allows a better adaptability of the screw position

(b) Only CT may demonstrate a horizontal fracture in the sagittal plane suggesting an eccentric application of the screw. A more oblique introduction of the screw, typical of the percutaneous fixation, means the risk of an ineffective fixation because the screw thread could not overcome the fracture line.

In clinical practice in some cases, scaphoid morphology and fracture orientation may allow many possible screw orientations on the sagittal plane, still introducing the screw from a tuberosity's "safe zone", without violating the ST joint. This makes percutaneous fixation easy to be performed. In other cases scaphoid morphology and fracture orientation may limit a screw placement biomechanically acceptable on the sagittal plane, and percutaneous fixation become difficult to be performed (Fig. 15.1). Therefore CT informations on the scaphoid sagittal plane are important for the surgical strategy!

I personally believe that retrograde volar screw fixation, regardless if open or percutaneous, consists in finding a compromise between the variable bone morphology and the variable spatial orientation of fractures and nonunions. In the coronal plane, sometimes it is more appropriate to introduce the screw in an oblique direction through the tuberosity [13], other times in a central position in relation to the longitudinal axis of the scaphoid [12] (Fig. 15.2).

The same occurs in the sagittal plane: sometimes the screw has to be more appropriately introduced in an oblique direction toward the dorsal aspect of the proximal pole and sometimes has to be eccentrically applied (Fig. 15.3).

In my opinion choosing between an open fixation and a percutaneous fixation should take into consideration these biomechanical aspects. Anyway, when you choose a percutaneous fixation, you have to take into consideration a possible mini-open approach to the tuberosity for an easier proper insertion of the guidewire. Guidewire insertion is the critical step of the procedure. Scaphoid central axis is partially or completely obstructed by the trapezium, and this requires finding a more oblique-radial direction for inserting the guidewire. Several researchers have attempted to quantify the optimum starting position for screw insertion so that the screw ends up in the center of the proximal pole and at the same time avoid coming out from the concave volar surface of the scaphoid. Some authors tried to solve the problems due to the trapezium in the application of the screw in the sagittal plane [116, 117], proposing to remove an anterior portion of the trapezium or directly to ream through the trapezium [97] to gain access to the scaphoid. Other authors have localized a "safe zone" [118] on the tubercle through which to determine an optimal introduction of the screw, without having to remove an anterior bit of trapezium.

All these important opinions suggested me to focalize the problem about the trapezium, developing a special guide for the guidewire, with a pointed extremity in order to grasp the scaphoid's tuberosity on the top and to push back the trapezium for a deeper screw introduction, when necessary (Fig. 15.4a, b).

Another important feature is that, for each length, the headless screw selected has a long and short leading thread, to better adapt to the variable size of the proximal pole, both in fractures and, above all, in nonunions.

In *waist nonunion* you can choose a long leading thread to improve the rigid fixation. In the coronal plane, the shape of the CS graft, wedge or trapezoidal, depends on the morphology of the nonunion, and this is important above all in the sagittal plane, because you have to correct the associated carpal instability just with the insertion of the CS graft. Usually a superficial introduction of the screw on the tuberosity in relation to the ST joint and an oblique insertion, easier to perform, allows to easily cross the nonunion site while utilizing a long leading thread screw (Fig. 15.5a).

On the contrary, in *junctional* nonunion, after debridement and bone graft insertion, the residual portion of the proximal fragment only allows the use of a short leading thread screw that has to reach the very end of the proximal pole. Usually a deeper introduction of the screw in relation to the ST joint and an eccentric volar insertion is necessary for a proper stable fixation. And the more horizontal is the orientation of nonunion,

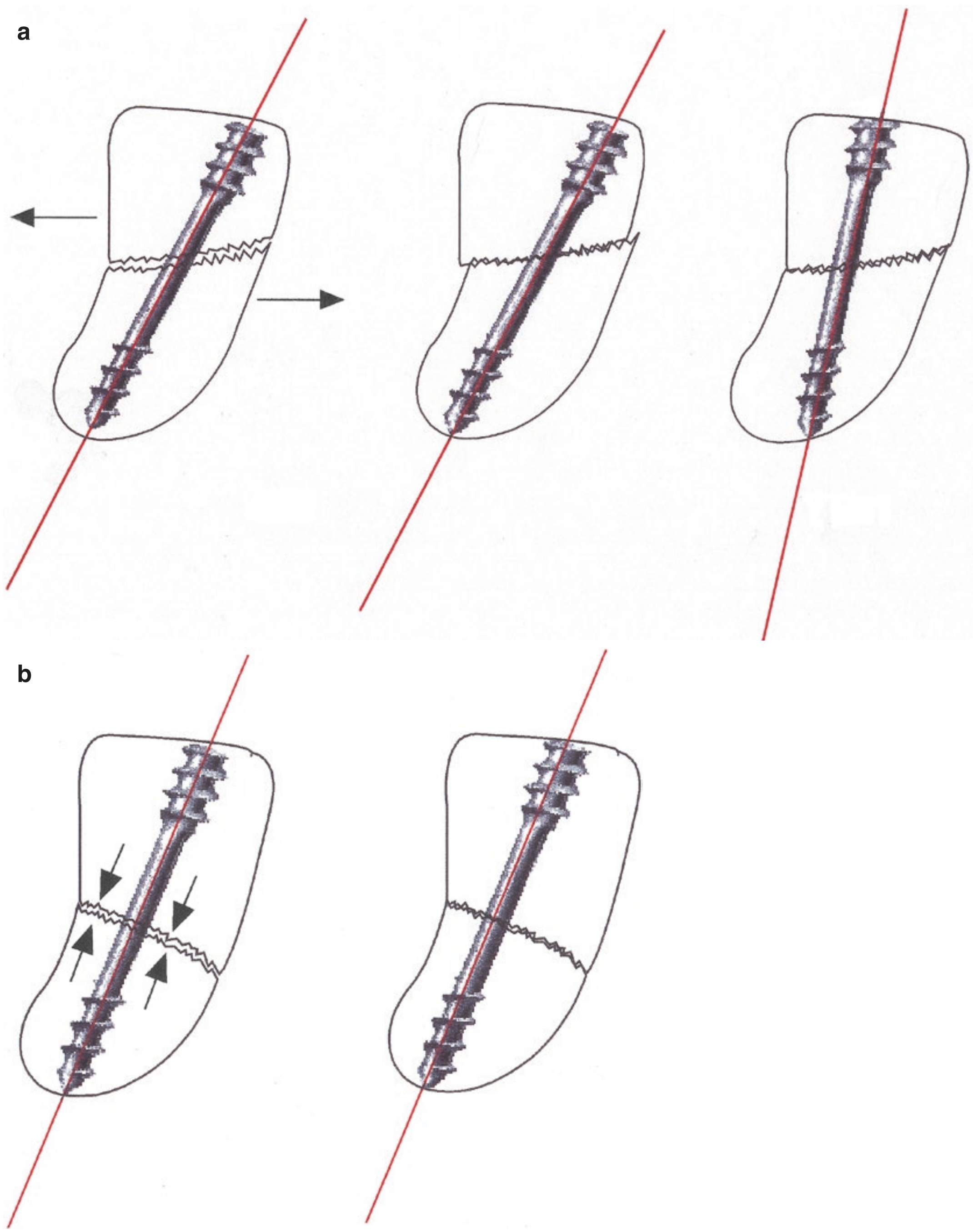


Fig. 15.2 (**a**) In a horizontal fracture, a screw applied along the longitudinal axis of the bone may submit the proximal fragment to sliding forces, and this risk increases in relation to the compression capacity of the screw. (**b**) In a transverse fracture, compression forces along the longitudinal axis stabilize the fracture

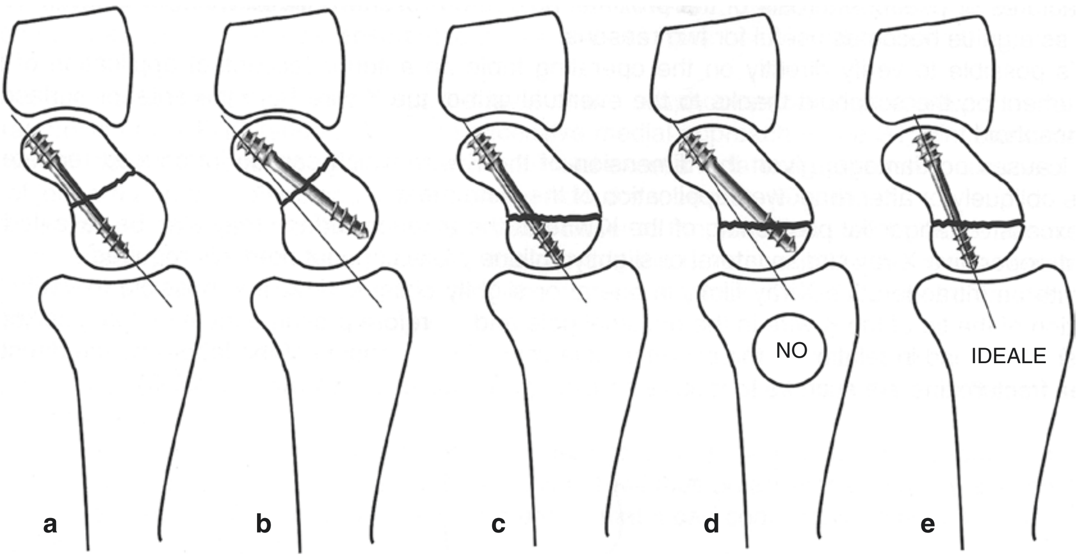


Fig. 15.3 The examples represent the extremes of a range of possible spatial orientation of fractures or nonunions, from the easiest to handle (**a**), also percutaneously (**b**), to the most difficult (**c**, **d**), and the relationship between the line of introduction of the screw and the anatomical link of the trapezium. Often an ideal introduction of screw (**e**), according to the biomechanics, isn't really feasible, if not through a transtrapezial approach [11, 12]

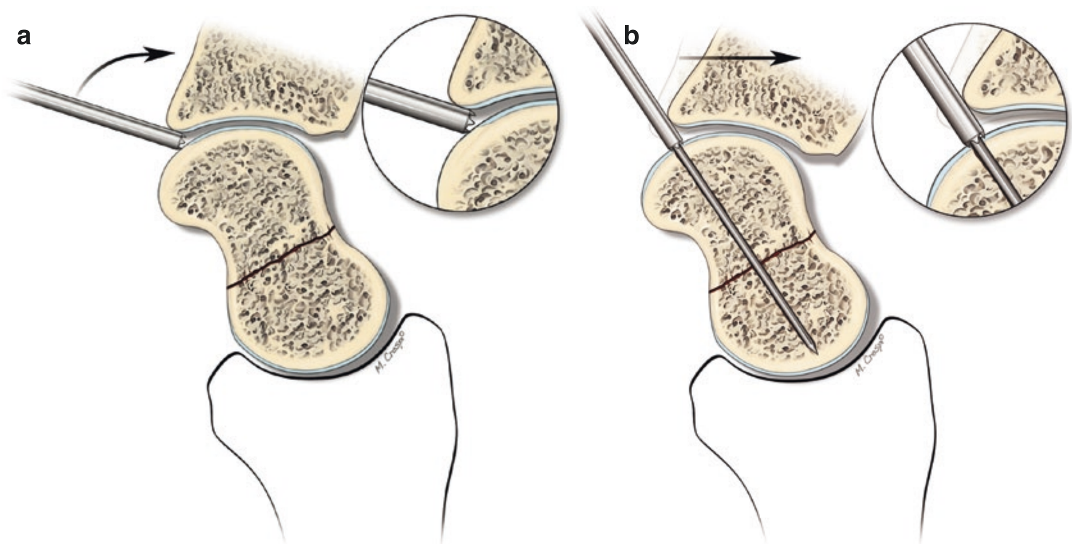


Fig. 15.4 The presence of the trapezius can hinder the appropriate retrograde introduction of the screw. With a special guide for the guidewire, with a pointed extremity it is possible to grasp the scaphoid's tuberosity on the top and to push back the trapezium for a deeper screw introduction, when necessary (Fig. 4 **a**, **b**)

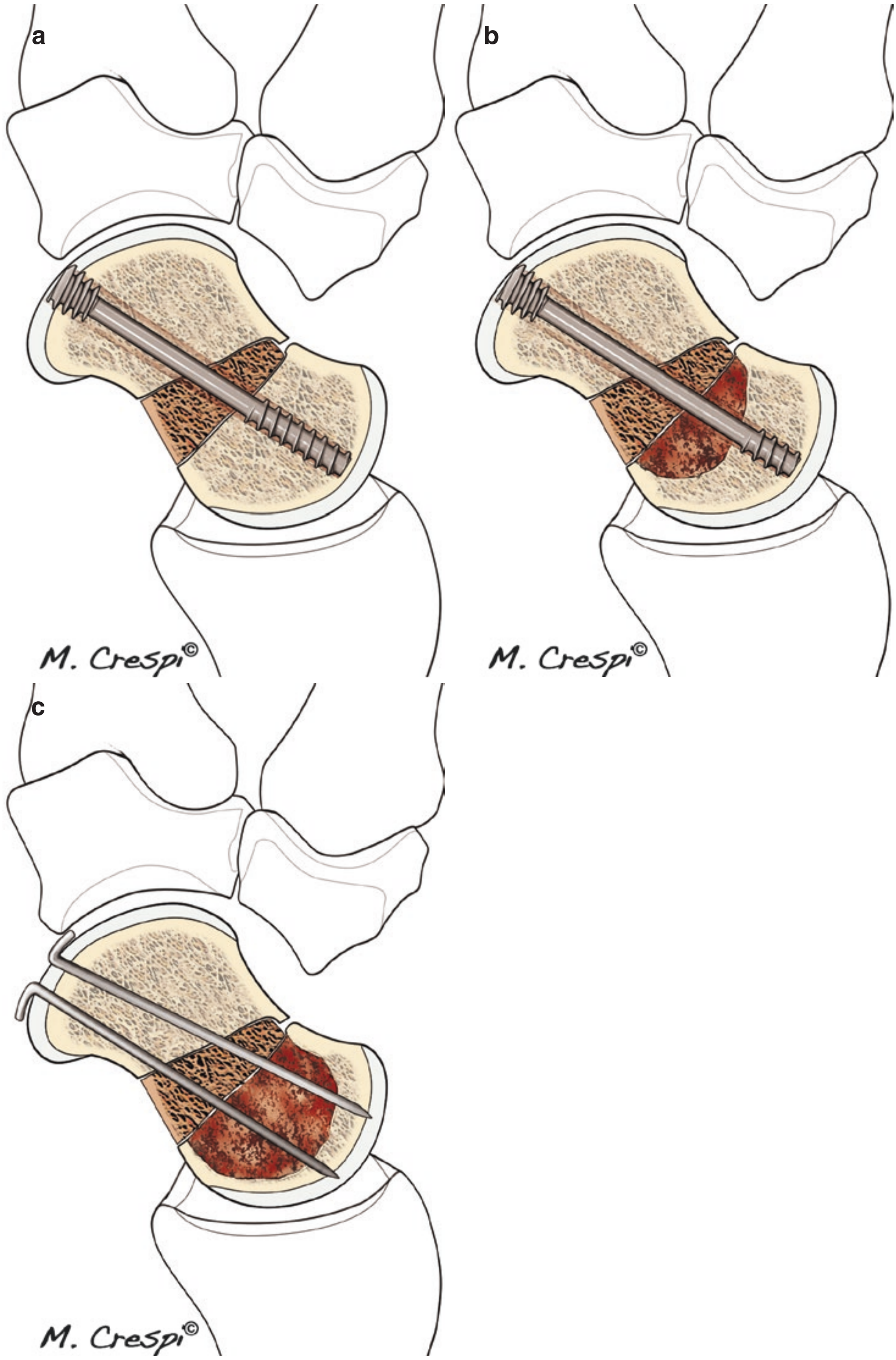


Fig. 15.5 (**a**) In *waist nonunion* a superficial introduction of the screw on the tuberosity in relation to the ST joint and an oblique insertion allow to easily cross the nonunion site while utilizing a long leading thread screw. (**b**) In *junctional* nonunion, after debridement and bone graft insertion, the residual portion of the proximal fragment only allows the use of a short leading thread screw that has to reach the very end of the proximal pole. (**c**) When, after debridement, the proximal fragment is completely empty, it is possible to perform a stable fixation using one or two K wires, perfectly bended around the tubercle in order to be left in situ for a long time, usually without a functional limitation of the wrist

the deeper is the ST joint, and the more eccentric has to be the screw introduction (Fig. 15.3c).

Anyway CT scan sagittal plane preoperative evaluation imaging may suggest the most appropriate screw introduction line in relation to the amount of residual bone that can be fixed by a screw (Fig. 15.5b). When, after debridement, the proximal fragment is completely empty, only Kirschner wires can get a stable fixation as well (Fig. 15.5c).

In performing a volar retrograde screw fixation, the wrist is supinated on the operating table with a light traction applied on the thumb alone, using a single Chinese finger trap [19, 69]. This position extends the scaphoid, and ulnar deviates the wrist to improve access to the distal pole of the scaphoid opening the ST joint space and helping in avoiding the trapezium.

Of course in case of a very proximal nonunion, a dorsal approach and a mini-headless self-cutting screw have to be chosen.

I want to underline that in dorsal fixation too, nonunion spatial orientation may get fixation sometimes more difficult, due to the dorsal rim of the radius.

Even in this case, a special pointed guide for the guidewire is useful not only to protect soft tissues but also for a stable grasping of the proximal pole on the vertex and for choosing the proper direction of guidewire insertion.

15.11 "Imaging" a Scaphoid Nonunion

As the understanding of fragments alignment and scaphoid morphology is important for effective fixation both of fractures and nonunions, more than MRI, CT scan has become a very useful and widely used preoperative imaging technique [54, 55, 119].

Particularly percutaneous fixation has stimulated the research in the field of computer-assisted technology, because biomechanical studies have shown that maximizing central placement [8, 15, 120] of the screw improves the stability of fixation and may promote a more favorable clinical outcome.

But the morphology of the scaphoid is highly variable so the location of the central axis is inconsistent. Moreover in the volar approach, the trapezium may impede the access to the central axis, and central placement of the screw may be difficult to achieve [7, 121, 122].

Preoperative CT scan of scaphoid is of great value to assess the "personality" of a fracture [123]. This includes an understanding of the fracture location, comminution, deformity and vascularity. In established nonunion helps in identifying avascular necrosis, in choosing the best management option and in predicting the outcome of bone grafting procedures [123].

Since 5 years, I have been using cone beam computed tomography (CBCT): a new low-dose high-resolution imaging technique [65–67] that generates a 3D image. In this way I can choose the most appropriate surgical approach based on the above highlighted variables: scaphoid morphology and spatial orientation and location of the nonunion. Whereas by CT scan you can deduce even the biological aspect thanks to the study of bone density, MRI is less and less used as a preoperative diagnostic tool. Any increased radiodensity seen on CT scan should be considered a true difference in bony density, different from the relative increased radiodensity seen in plain radiographs, as a possible sign of the hyperemia of the proximal fragment during the healing phase of scaphoid fractures [104, 123–125] or sometimes due to the rotation of the proximal fragment that only simulates increased bone density [58]. The CBCT, because of its low-dose exposition, becomes also increasingly useful in post-operative evaluation of the appropriateness of the fixation and consolidation achieved, often replacing traditional X-ray control, in order to allow the patient to start safely an early active mobilization. Anyway, also from a medicolegal point of view, when treating a long-standing nonunion, above all in athletes, a preoperative MRI to rule out avascular necrosis of the proximal fragment is advisable.

15.12 The Bone Graft in Scaphoid Nonunion

In delayed union and fibrous nonunion (type D1), without evidence of avascular necrosis, a percutaneous fixation is now the gold treatment [75, 76, 126, 127]. Tissue perfusion at nonunion site may be preoperatively demonstrated by enhanced MRI with gadolinium, and this guarantees the quality of the interposed tissue and its capability to heal when a rigid fixation alone, without any bone graft and with a self-compressive headless screw, is performed.

When type D2 nonunion, without intrascaphoid deformity, occurs at the waist level, a spongious bone graft from distal radius is the treatment of choice or, as lately proposed, even from olecranon [128], even if less invasive techniques, such as percutaneous bone grafting with arthroscopic assistance, have been proposed [129].

In type D3 nonunion at waist level, when humpback deformity is evident, a conventional corticospongious (CS) nonvascularized bone graft (NVBG) from iliac crest has to be used, even in the presence of loss of blood supply. Rigid fixation is capable to obtain revascularization of the necrotic proximal pole [79]. If fixation is stable, the necrotic bone can be revascularized through the "creeping substitution" process [7, 19, 130–134].

Rather than using the traditional iliac crest corticocancellous bone graft, which is fraught with morbidity risks [135], the distal radius because of its proximity to the scaphoid, its rich supply of cancellous bone graft and its ease of harvest is increasingly used as donor site of the bone graft. The new trend is to obtain a structural CS bone graft from the radius, capable of lengthening the scaphoid, and to resist the compression forces produced by a headless self-compressing screw. Results may be as gratifying as the results obtained with a conventional CS graft from iliac crest, also in case of AV necrosis of the proximal pole [7, 19, 136, 137].

In junctional nonunion, or anyway when debriding the nonunion site makes nonunion became "junctional", a combined approach as proposed by del Pinal allows inserting a corticospongious graft volarly and fixing the scaphoid dorsally [105].

But, as already said, it is possible to treat this troublesome pattern of nonunions, with a retrograde volar fixation by using a short leading thread screw.

In case of a proximal pole nonunion, a dorsal approach is mandatory. The nonunion has to be debrided, and the gap filled with spongious bone graft harvested from the distal radius. The proximal pole is fixed with a mini-headless screw.

Every time there is the need to facilitate fracture healing, such as proximal pole nonunions, particularly when treated with vascularized bone grafts, a bone stimulator has been advocated with evidence effectiveness in accelerating scaphoid nonunion healing [138].

15.13 Failed Fixation

In failed fixation, if the screw is in an incorrect position but the bone quality of the proximal fragment is still good, screw fixation can be repeated.

In failed fixation, when the screw is in a correct position, which means centrally placed in the proximal pole, the screw may be replaced with a "peg" graft introduced in a "press-fit" way inside the scaphoid and associated with a "horseshoe" graft to fill the volar gap [7, 19] (Fig. 15.6). Usually the stability of this biological fixation allows an early active mobilization and a clinical and radiological early healing. The "peg" graft can also be harvested from the radius, requiring in this case a more delicate handling of the graft when it is inserted inside the scaphoid along the track of the screw. When it is impossible to obtain a good "press fit", a fixation with two K wires may be an ideal compromise. All these are typical conditions where combining a biophysical stimulation of osteogenesis, as described in the dedicated paragraph, is an option to be considered.

In case of poor bone quality in the proximal pole, the "peg" graft from iliac crest may be augmented with a "bundle implantation" as suggested by Horii-Fernandez [83, 84].

A new volar scaphoid miniplate has been recently proposed in these kinds of failed fixations, when the bone quality of the residual proximal pole is poor, so preventing the possibility of a new screw fixation [139, 140].

The plate fixation was then extended, as primary indication, for nonunions particularly difficult due to the proximal pole size and trophism. With this miniplate up to three 1.5 mm locking screws can be placed on each side of the nonunion. Early mobilization is possible due to angular stability of the device.

15.14 Avascular Necrosis of the Proximal Pole

The distribution of vascular supply comes through ligamentous attachments: one third from the tuberosity and proximal two thirds from the dorsal ridge. So, it could be simple to explain the

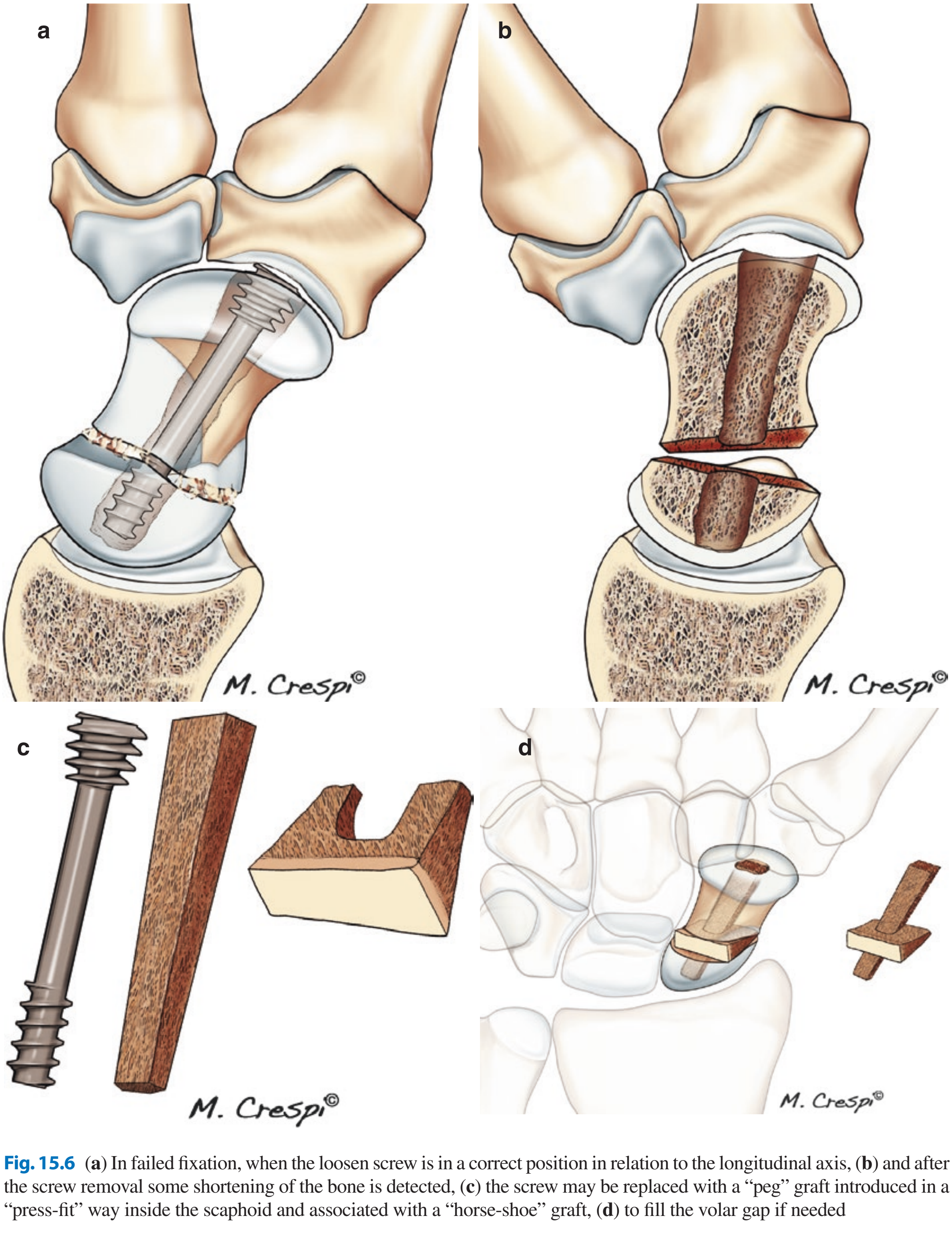


Fig. 15.6 (**a**) In failed fixation, when the loosen screw is in a correct position in relation to the longitudinal axis, (**b**) and after the screw removal some shortening of the bone is detected, (**c**) the screw may be replaced with a "peg" graft introduced in a "press-fit" way inside the scaphoid and associated with a "horse-shoe" graft, (**d**) to fill the volar gap if needed

trouble of vascular supply in the proximal pole in case of a fracture, but a vascular supply through the deep radioscapholunate ligament has been considered by Kauer [141], and this can explain why, in proximal pole nonunions, sometime some proximal poles are still vascularized and sometime are not (Fig. 15.7).

This can also justify MR imaging of vascularized tissue at the apex of the proximal pole, and this helps when we set the therapeutic strategy (Fig. 15.8).

There is still no consensus on definition of avascular necrosis of the proximal pole. Many optimal means to determine vascular supply have been described, X-ray, CT, MRI, histology or bleeding points at surgery, even if the absence of proximal pole bleeding seems to be the main diagnostic element for a true vascular impairment [56].

In the literature we find acceptable union rates in fixing the proximal pole with a nonvascularized bone graft (NVBG) from iliac crest even in the presence of poor or absent vascular supply [142–148].

NVBG may be preferred as it is less technically demanding, and the compression exercised by a Herbert-type screw fixation is capable of compensating for the greater biological stimulus of the vascularized bone graft (VBG), but which is otherwise more fragile, mostly fixed with K wires so producing a less stable fixation.

And we always must remind that stable fixation means revascularization of avascular bone through the creeping substitution process.

Moreover a traditional volar NVBG, that is to say "Graft what you really need", allows an easier anatomical reconstruction, saving more easily partially or completely the volar ligaments, compared to a VBG, which requires a more extensive volar approach, with the tendency to remove more bone than what you really need.

There is a general consensus about the indications of a VBG: a truly avascular necrosis in the proximal pole and a secondary reconstruction after failed fixation with NVBG.

The most utilized techniques proposed for avascular proximal pole scaphoid reconstruction are dorsal pedicled VBG [92–94, 149, 150], volar pedicled VBG [89] and free corticocancellous MFC graft [151–153], and for the less common proximal pole replacement are free osteochondral MFC graft [154–157], free coracoid graft [158] and free osteochondral rib graft [159–162].

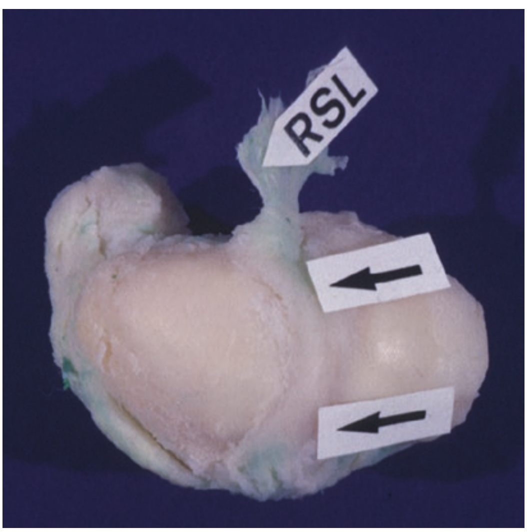


Fig. 15.7 Specimen of scaphoid injected showing the deep RSL ligament as a possible vehicle for vascular access to the proximal pole

Fig. 15.8 T1-weighted coronal image demonstrates heterogeneous proximal pole signal with areas of fat signal remaining at the apex of the proximal pole meeting the criteria for viability

In proximal pole reconstruction, the choice among a dorsal or volar pedicled vascularized bone graft or a free vascularized bone graft depends not only on the pattern of nonunion but also on the surgeon's personal attitude toward a particular kind of vascularized graft.

Among all the VBGs, after an undisputed dominance of the dorsal Zaidenberg bone graft [92] today, the most used is the volar bone graft proposed by Kuhlmann [89–91]. First described for a failure of the classical techniques is now recommended as a primary treatment of scaphoid nonunion to speed consolidation [95].

The value of a primary vascularized bone graft pedicled on the transverse volar carpal artery is because this technique may be performed as a day of admission surgery, through a single incision under locoregional anesthesia as a primary intervention.

Many studies reported a better consolidation rate with this kind of VBG [90, 91, 163–166], but, as Mathoulin [91] itself declares in his study, too many variables exist in vascularized nonunions to validate today the use of a VBG also in a classic vascular nonunion.

Moreover we have to consider the limit, recognized by literature, of a pedicled VBG. Even if you are extremely precise in harvesting the graft, if you don't want to disturb the delicate equilibrium between the pedicle and the bone graft, the fixation is often less stable than what you could get with a screw, because it often requires Kirschner wires to avoid the risk of destroying the bone graft, thus aiming more to biology than stability, so requiring longer period of immobilization to reach a sound consolidation (Fig. 15.9).

As an alternative, if one wants to aim to the stability of fixation more than biology, two aspects that are not always possible to combine in a therapeutic strategy of an avascular scaphoid nonunion, one may choose a NVBG and perform a more stable fixation with a new-generation self-compressive headless screw, which is easier to perform than a VBG, which needs to be harvested with a long pedicle, making the procedure more demanding. Screw fixation, when stable, may provide revascularization of an avascular proximal pole with a classic NVBG, as long as the proximal pole size is appropriate for screw fixation (Fig. 15.10).

In practice, considering that most of the proximal scaphoid nonunions have the need for anterior bone grafting, until there is bone to be fixed with a screw, the best approach is to perform a stable screw fixation through a volar approach.

Only in case the proximal pole is completely emptied, and then a screw doesn't have enough bone on which engage, the "evergreen" Kirschner wires can lead to a stable fixation as well (Fig. 15.11).

Whatever the fixation device utilized, in junctional or proximal pole avascular nonunions, biological conditions are unfavorable for a rapid bone consolidation, above all when using a NVBG, and it is reasonable to stimulate the osteogenesis process with a capacitive system, as it will be described more ahead in the dedicated paragraph.

If then, the graft is harvested from metaphyseal distal radius; a possible role in indirectly stimulating the bone healing may be due to a "core decompression" effect [167].

We must therefore conclude that, just when we thought we had reached a consensus about the indications of VBGs for proximal pole reconstruction, up to now there is no evidence for technique superiority between VBGs and NVBGs in terms of rate of union [168].

And they are always more authors who propose a NVBG in the treatment of scaphoid nonunion, regardless the vascular status of the proximal pole. Vigorous curettage, dense packing with fresh autogenous nonvascularized bone from distal radius ("matchstick" of volar cortex and cancellous bone) and rigid fixation can lead to healing, regardless of vascular status of the proximal pole [169, 170].

The advent of arthroscopy has modified the approach to the management of scaphoid nonunion [100].

We have to underline that, since some years, arthroscopy has been proposed for proximal pole nonunion, even with vascular impairment, using obviously a spongious NVBG [99, 101] with very good results, proving once again that it is

Fig. 15.9 Waist nonunion (**a**) with avascular necrosis of the proximal pole (**b**). A Kuhlmann VBG is fixed with two K wires removed after 6 months (**c**), achieving the bone healing (**d**). With permission of F. Niestedt, Merano, Italy

stability of fixation, by means of screw or K wires, which creates the conditions for the revascularization of the proximal pole.

Caloia has even proposed the arthroscopic management of scaphoid nonunion without bone graft, in association with a distal radius "core decompression", in order to stimulate the osteogenic tissue interposed in the nonunion site.

This method is based on the osteogenic potential of pseudoarthrosis tissue and bone from scaphoid nonunions [171] and on the biological contribution of "core decompression" (increased

Fig. 15.10 (**a**) A 23-year heavy manual worker and kick-boxing practicing, right wrist. Junctional nonunion (**b**) with avascular necrosis of the proximal pole. No bleeding points were observed at surgery. (**c**) A nonvascularized bone graft (NVBG) from distal radius and a screw fixation has been performed. Sound consolidation may take a long time, but the patient is free to move the wrist, thanks to stability of fixation. (**d**, **e**) In this case a capacitive system has been early associated with a splint for 2 months to promote bone healing (**f**), also demonstrated by CBCT (**g**–**i**), and maximize the clinical result (**j**, **k**). This case may suggest a possible combined role of metaphyseal “core decompression” [167] in this sound radiological union, as it will be discussed in the following cases

Fig. 15.10 (continued)

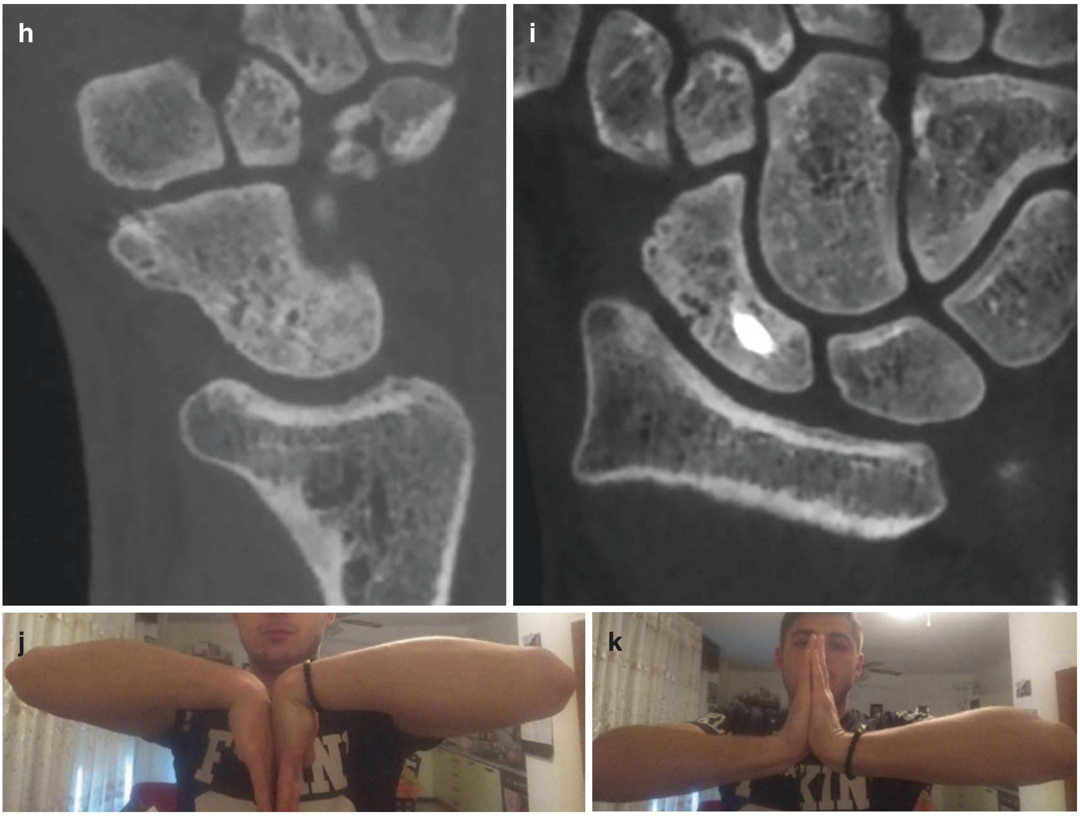


Fig. 15.10 (continued)

Fig. 15.11 (**a**) Proximal pole nonunion with (**b**) MR avascular necrosis in a 20 years karate practicing, left wrist. A CS bone graft was harvested from the distal radius. (**c**–**e**) X-ray and CBCT depict bone healing. A stable fixation was obtained using two K wires, still in situ after 16 years without a functional limitation of the wrist (**f**, **g**). Again, this case may suggest a possible role of metaphyseal core decompression [167] in this sound radiological union

vascular perfusion, release osteo-inductive factors rhBMP-2, osteoblastic stimulation, bone tissue regeneration) [167].

It is well known that the "surgical manipulation" of the end of the radius will incite hyperemia to accelerate revascularization of the lunate [167].

And more recently De Carli [172] has underlined how the distal radius "core decompression" can stimulate regional bone regeneration factors, such as the morphoprotein BMP-2.

But even the biophysical stimulation, which I routinely associate to the surgical treatment of scaphoid nonunions, has been recognized to be able to stimulate the bone morphoprotein BMP-2 (see related paragraph on Capacitive System).

And the great advantage is that this method can be applied very early, during the first period of immobilization by means of a modular splint.

So we can consider that, when treating a "difficult" proximal pole with a critical blood supply with a NVBG from distal radius, a biophysical stimulation can be added to a metaphyseal "core decompression" of the radius in stimulating bone regeneration factors (Figs. 15.19, 15.20, 15.21 and 15.26).

And the same considerations may arise spontaneously when facing the results of authors using a generous corticospongious graft from distal radius in the management of scaphoid nonunion [169, 170].

Nowadays arthroscopic bone grafting (ABG) is increasingly used in the management of waist and proximal pole nonunions, even with avascular impairment of the proximal pole. Moreover intrascaphoid deformity (HBD) can be corrected as well in the same arthroscopic procedure. After the proximal pole is nearly completely emptied, spongious graft from iliac crest is packed down, and the nonunion is stabilized with two or three K wires. For Ekker [103], in proximal pole nonunions, as long as the proximal pole is intact and the cartilage is good (CT scan is mandatory!), it is possible to have its revascularization. If you need more stability during the bone healing process, in order to allow an earlier active mobilization, one of the K wires can be exchanged by a screw. In proximal pole nonunions, regardless the vascular status, the first choice is an arthroscopic bone graft (ABG), or open surgery, but no more a VBG [103]!

Instead my first choice in an avascular proximal pole is an open NVBG, but through a mini-invasive volar approach, and screw fixation, until there is bone to be fixed with a screw, or Kirschner wires fixation, but these have to be applied in the proper way to get a stable fixation as well (Figs. 15.5, 15.19, 15.20 and 15.21).

Why a mini-invasive volar approach? For the following reasons:

- Easy anatomical reconstruction for savings both the volar ligaments
- Direct view on the volar "gap" and deformity
- Save the residual blood supply through the dorsal ridge and the deep RSL ligament
- Easy screw fixation with a short leading thread if possible
- Kirschner wires fixation, with the extremities easily bended and cut around the tubercle, arranging them in order to avoid any FCR tendon impingement
- Corticocancellous bone graft from radius (easy, same volar approach, "core decompression" effect)

In practice we can consider that in a mini-invasive volar approach, it is possible to reconstruct all the anatomical structures involved in the surgical approach, in order to be competitive with the arthroscopic bone graft technique, because the technical aspects of fixation and grafting are the same: the proximal pole has to be packed down by the bone graft and fixed.

But when harvesting the graft from the radius, you may also activate a radius metaphyseal "core decompression" effect that can be combined with a capacitive system stimulation of the osteogenesis when performing a really stable and longstanding fixation with the most easy-to-use device: the K wire!

And this is an important consideration to make when you have to "save" an avascular proximal pole nonunion in an active patient, above all if involved in high-level sport activity: make it easier if possible!

In conclusion, nowadays a NVBG, open or arthroscopic (ABG), may be a valid alternative to the VBG.

15.15 The Role of Capacitive System in the Management of Fractures and Nonunions of the Carpal Scaphoid

15.15.1 Introduction

In recent years, interest has focused on the use of physical energy to promote or enhance the healing of acute fractures and nonunions, and its clinical application is now based on sound scientific evidence. The biophysical stimulation techniques used in orthopedic practice are inductive (pulsed electromagnetic fields, PEMF), capacitive (capacitively coupled electrical field, CCEF) and mechanical (low-intensity pulsed ultrasounds, LIPUS) [173–176].

Electric and electromagnetic energy (CCEF, PEMF) can be applied to the human body by means of magnetic or electric field generators using adhesive electrodes or coils placed in proximity of the fracture. Mechanical energy (LIPUS) is directly applied to the body through a mechanical transducer.

There are various mechanisms of action by which osteogenesis is enhanced through the application of biophysical stimuli with these noninvasive methods. The cell membrane is the main site of interaction of these stimuli, and the preferential candidates are the membrane receptors and Ca^{++} channels [177].

PEMF stimulation causes the release of calcium ions (Ca^{++}) from the smooth endoplasmic reticulum, whereas with CCEF stimulation, an increase in Ca^{++} transport across voltage-gated channels is observed; for LIPU stimulation, the ideal candidates for performing this function would seem to be mechanosensitive ion channels, although a true mechanoreceptor has yet to be identified. The intracellular increase of Ca^{++} triggers a series of enzyme responses with resulting gene transcription (several bone morphogenetic proteins, BMPs), transforming growth factor-beta (TGF-β1), collagen and cell proliferation [178, 179].

In vitro studies have shown that physical stimuli increase bone matrix synthesis and favor the proliferation and differentiation of the primary osteoblast-like cells [180–182].

Fassina et al. investigated the effect of PEMF on SAOS-2 human osteoblast proliferation and on calcified matrix production over a porous polyurethane scaffold and showed higher cell proliferation and greater expression of decorin, fibronectin, osteocalcin, osteopontin, TGF-β1, type I collagen and type III collagen in PEMF-stimulated culture than in controls [183].

Hartig et al. demonstrated that exposing primary osteoblast-like cells to CCEF increases the synthesis of bone matrix and favors their proliferation and differentiation [181].

Ryaby et al. reported that LIPU increased calcium incorporation in bone-cell cultures, reflecting a change in cell metabolism [184]. This increase in second messenger activity was paralleled by the modulation of adenylate cyclase activity and TGF-b1 synthesis in osteoblastic cells.

A number of experimental studies, in various animal models, have shown more rapid bone tissue formation and a shorter healing time for experimental fractures and/or in bone lesion studies [185–188].

It has, indeed, been possible to quantify the effect of PEMF stimulation on the mineral apposition rate, which increases by 80% [189].

In experimental fractures produced on rabbit fibula, a significant reduction in healing time was observed when using CCEF [177].

In the presence of castration-induced osteoporosis in rats, CCEF was seen to inhibit the onset of this condition [190].

Wang et al. studied the healing of bilateral closed femoral shaft fractures in rats reporting a 67% increase in stiffness in the group treated with LIPU, which was significantly greater than the increase observed in the controls [191].

Physical agents may be synergistic with endogenously synthesized or exogenously applied growth factors in tissue repair; the application of physical stimuli results in changes in gene expression for signaling proteins. The interactions between growth factors and physical stimuli are a very fertile area for clinical investigation.

Over the past few years, since the biophysical stimulation of osteogenesis has become part of clinical practice, a great deal of clinical trials has been performed using appropriate double-blind or control-group protocols [192–203].

These study designs were dictated by the need to make an effective distinction between the effects of biophysical stimulation and other possible associated orthopedic approaches and to quantify the efficacy of the treatments in favoring bone consolidation in humans.

Some fracture patterns that occur in specific bones may compromise the blood supply or may severely impact the surrounding soft tissues. These fractures should be considered as being at risk, because they are more likely to result in delayed union or nonunion. At-risk fractures amount to 20% of all fractures. Biophysical stimulation has been seen to be capable of accelerating the healing of fractures treated with plaster cast or external fixation or complex fractures with serious soft tissue damage and bone tissue exposure [204, 205].

Biophysical stimulation finds just indication in all those cases in which the fracture site and morphology, type of exposure or patient conditions suggest difficulties in the repair process and biophysical stimulation succeeded in shortening the average healing time in all cases (25–38%) [206].

It is well known that fractures of the carpal bones such as the scaphoid bone, the lunate bone and the hook of the hamate bone require long healing times.

Conventionally, in the treatment of hand and wrist injuries, PEMF and CCEF are applied in delayed unions or established nonunions.

More specifically, despite the technological evolution of the fixation devices developed for the scaphoid bone over the past 20 years, CCEF has often been used to treat scaphoid nonunions and, recently, even acute fractures [207, 208].

In the 1980s, the techniques used to apply direct current required invasive procedures and therefore offered few advantages over surgical reconstruction procedures involving bone grafts [209, 210].

With the introduction of PEMF and CCEF, by means of superficial coils or adhesive electrodes, the advantages of a completely noninvasive technique that could be used in ambulatory settings became obvious [185].

More specifically, nowadays the use of special splint means that adhesive electrodes can be applied to the skin at an early stage that is usually destined for immobilization alone [211].

Afterwards, the simultaneous use of biophysical stimulation and static splint, which can be easily converted into a static-dynamic rehabilitation system with dedicated application kits, permits a global treatment of that fracture [211].

The importance of combining biophysical stimulation, both PEMF and CCEF, with rigid immobilization in the treatment of scaphoid fractures and nonunions has also been highlighted [212, 213]

Moreover, the site of fracture or nonunion would also appear to influence treatment, though data available in literature suggest that nonunions with a duration of more than 5 years respond less well to biophysical stimulation treatment [211, 214, 215].

To date there are still no studies comparing conservative treatment with or without biophysical stimulation in fresh scaphoid bone fractures, which explain the reluctance to use this therapy.

The effectiveness of a combined treatment (CCEF + splint) in reducing the healing time in scaphoid fractures and nonunions has recently been proposed [4].

The CCEF stimulation device (Osteobit®, IGEA SpA, Carpi, Italy) consisted of a rechargeable battery-powered generator delivering a density current of 25 μA/cm^2 to the treatment site. Two hydrogel electrodes were placed on the skin on either side of the fracture.

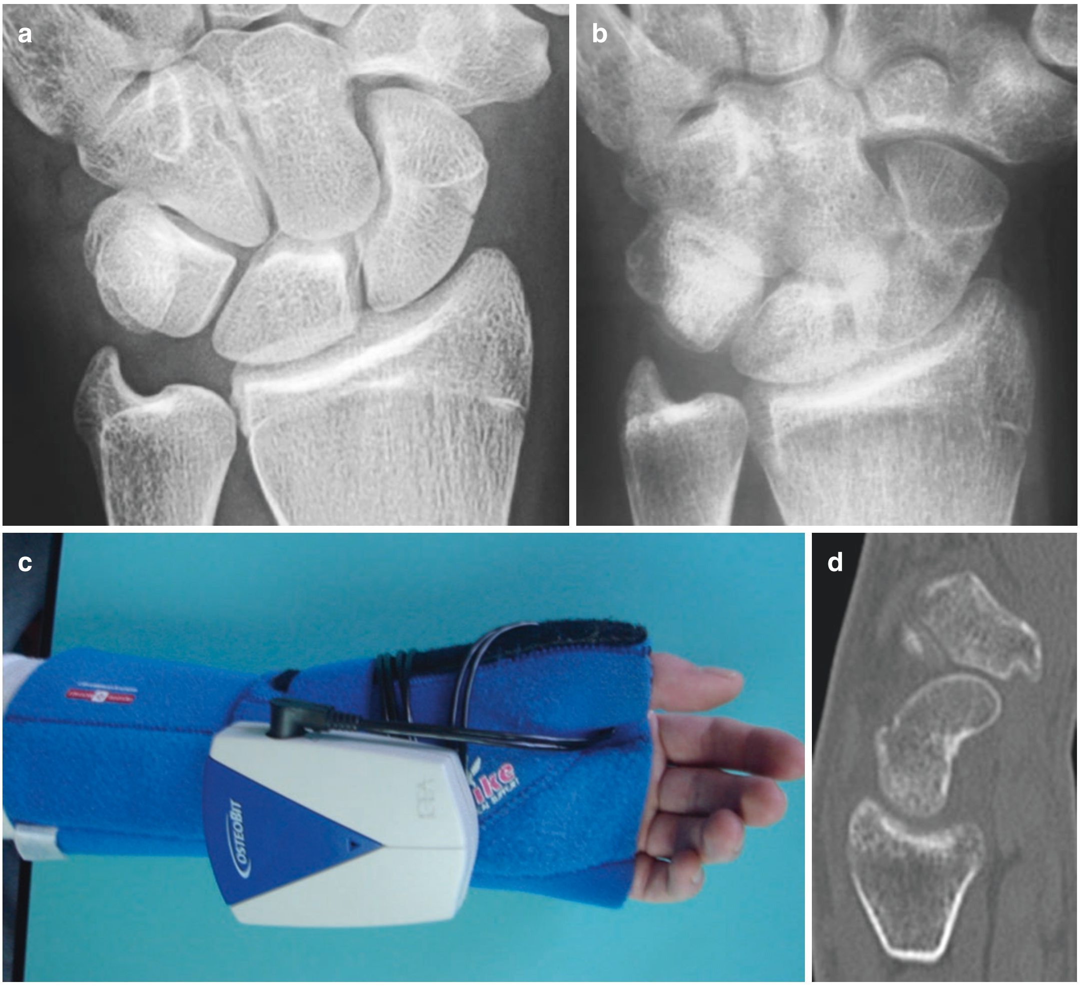


Fig. 15.12 (**a**) Apparently incomplete fracture of the middle 3rd in an 18-year-old student. Suggested treatment consisted of immobilizing the wrist and thumb with a modular splint, used in combination with Osteobit® for 30 days and subsequently at night-time only for a further 20 days, whereas during the day, the patient was allowed to return to active movement. (**b**) Follow-up X-ray performed after 30 days. (**c**) Example of splint application with Osteobit®. (**d**) CBCT after 50 days depicting bridging trabeculae at the fracture site

A microprocessor made it possible to monitor patient compliance in terms of hours per day. The stimulator's lightweight and compact design makes it portable and fully compatible with everyday activities. A Borelli static-dynamic splint to apply the stimulator has been used. Fifty-five scaphoid fractures and nonunions received the combined treatment (CCEF + splint). Healing time was relatively shorter than expected considering the difficulties often occurring in the management of fractures and nonunions of the carpal scaphoid.

The combined use of CCEF and splint consequently reduced the potential damages related to a prolonged immobilization. In all cases, therapy was well tolerated by patients, and compliance was excellent.

Thanks to this clinical experience I kept on using the rationale of this approach in the management of fractures and nonunions of the carpal scaphoid.

Fig. 15.13 (**a**) Transverse fracture of the middle third of the right scaphoid bone in a 33-year-old patient, employee. (**b**, **c**) MRI shows favorable prognostic factors for the biophysical stimulation of osteogenesis. Using the wrist and thumb modular splint allows the patient to choose whether to apply Osteobit® during the day or at night for 8–10 h and to continue, albeit with certain restrictions, his work as employee. (**d**) The X-ray, performed after 1 month, depicts bone consolidation and makes it possible to allow, given also the patient's job, a return to active movement and work. The patient did not require any further follow-up X-ray, reassured by the absence of any problems and full recovery of joint movement within 30 days. (**e**, **f**) MRI was ordered after 4 months in order to evaluate the biological signal of bone healing

15.15.2 Discussion

We are all familiar with the intrinsic risk of noninvasive treatment of a waist scaphoid undisplaced fracture, i.e. despite a lengthy and tedious immobilization period, the fracture may be subjected to delayed union, a risk that is further increased if the fracture has a more proximal location.

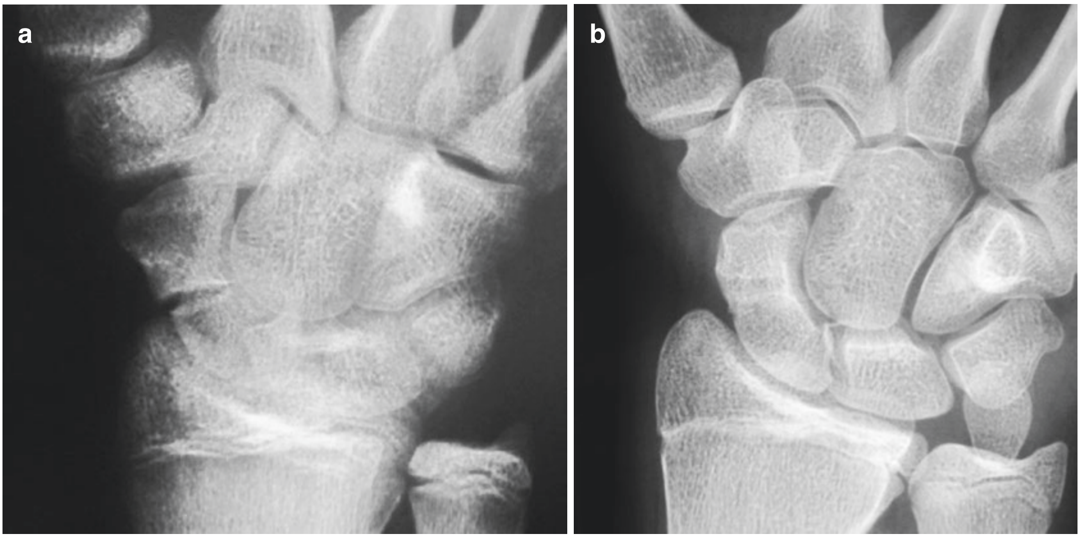


Fig. 15.14 (**a**) A 17-year-old student, who was referred after 2 months of treatment with a plaster cast. X-ray depicts a delayed union ("nascent nonunion"). (**b**) X-ray after 45 days of treatment with Osteobit® and splint and a further 30 days of treatment with Osteobit® at night-time only

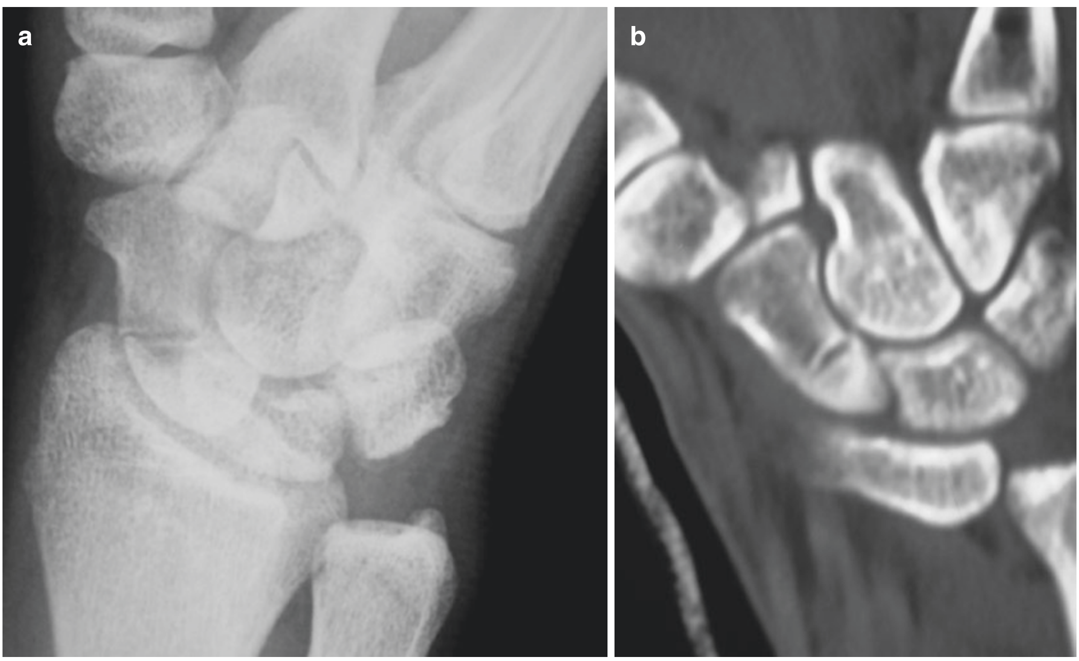


Fig. 15.15 (**a**, **b**) A 21-year-old student. X-ray and CT images of delayed union after 40 days of treatment with a long-arm thumb spica cast. A carpal diffuse reduction in bone density can also be seen. Although mini-invasive open or percutaneous fixation could have permitted immediate movement, the patient opted to continue conservative treatment with Osteobit® and splint for 2 months. (**c**) MRI showed favorable prognostic factors for (**d**) the biophysical stimulation of osteogenesis. (**e**) After 2 months (40 days of continuous use and 20 days of weaning day-time use of the splint), the X-ray showed apparent union, and the patient was able to use his wrist again normally. (**f**) After 2 more months, due to the persistence of mild pain under strength, a CT scan was ordered, which confirmed that union had been achieved. The patient does not complain of any problems at the current time

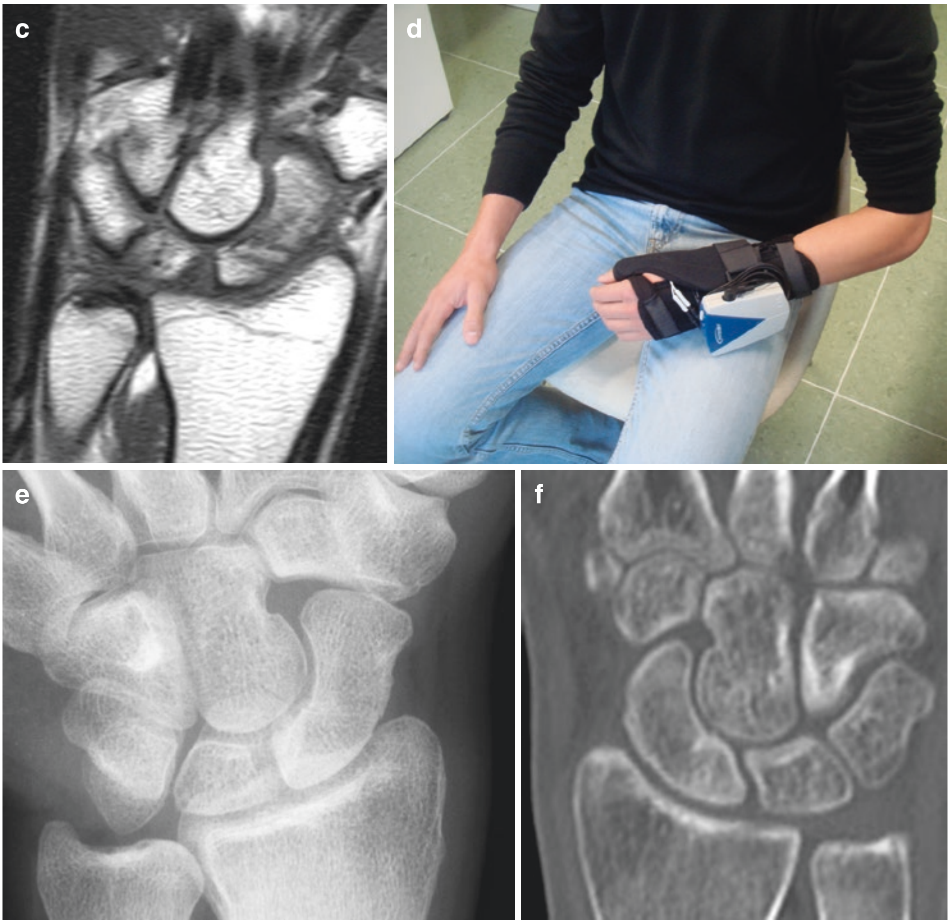


Fig. 15.15 (continued)

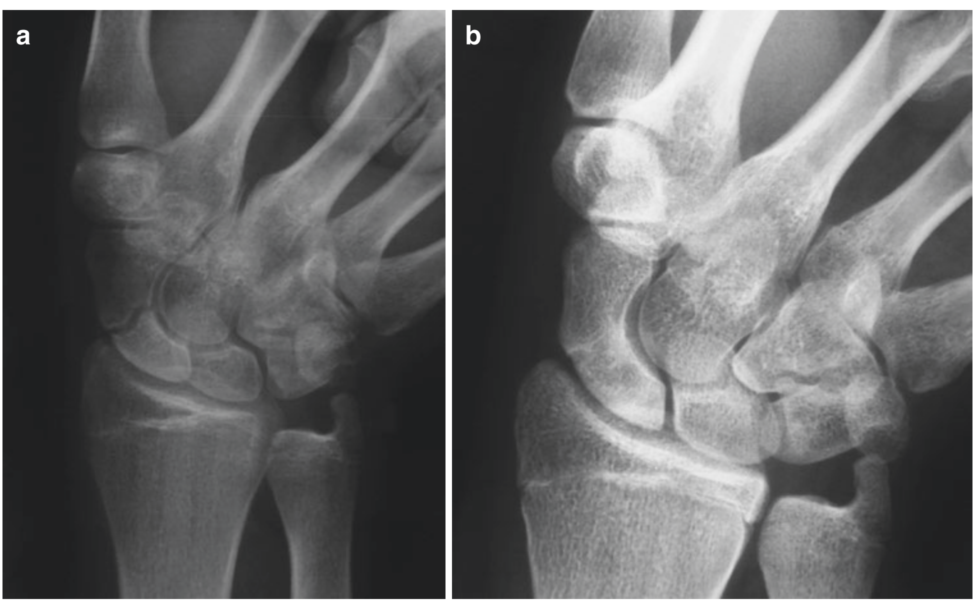


Fig. 15.16 (**a**) Delayed union in a 16-year-old student. (**b**) X-ray after conservative treatment with splint and Osteobit® for 2 months

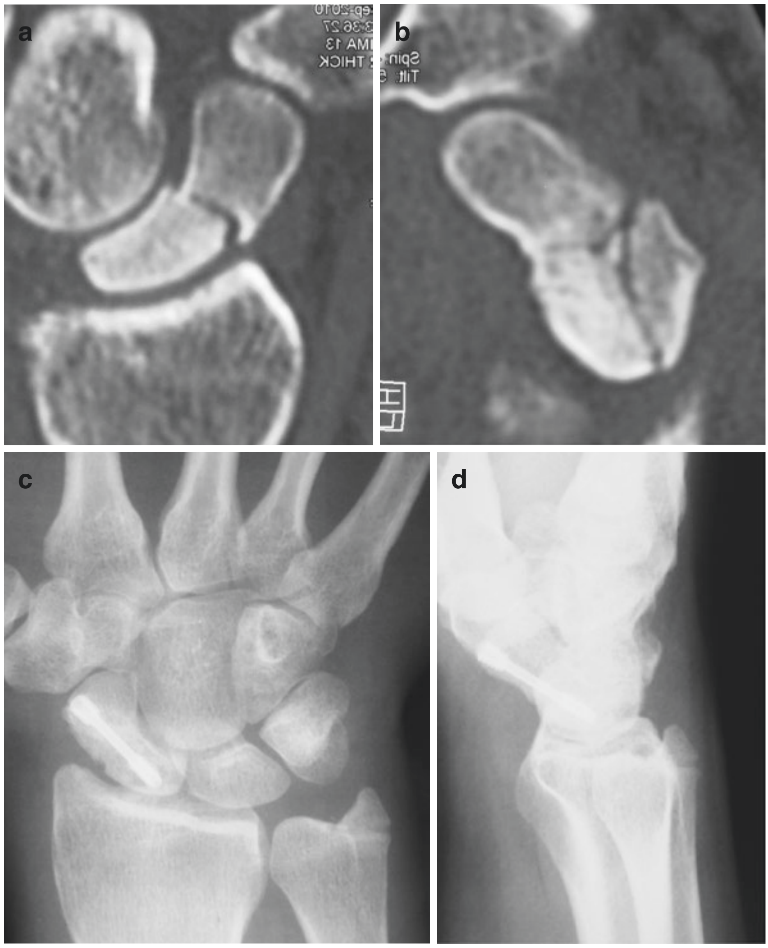


Fig. 15.17 (**a**, **b**) Percutaneous volar fixation combined, from the outset, with a modular splint and Osteobit® in a patient with delayed union who was referred 40 days after the injury. (**c**, **d**) The X-ray after 2 months showed that union had been achieved

Whereas surgical treatment favors union by creating a condition of stability in the fracture site, but it does not alter a precarious blood supply condition in the proximal fragment, a condition that can delay the osteogenesis process.

Capacitive system accelerates osteogenesis, as has been extensively demonstrated in literature, and if its use can be brought forward to a phase that is usually destined for an "idle waiting" in a plaster cast, this brings an undeniable advantage.

New-generation fixation devices, based on headless self-compressing screws with variable proximal thread sizes and the new increasingly minimally invasive fixation techniques, have undoubtedly broadened the indication for surgery not only to fractures of the proximal third but also to stable, undisplaced fractures of the middle third, which are currently often treated by percutaneous fixation techniques.

However, there is still a "borderline" between minimally invasive surgical treatment that can now be proposed supported by scientific evidence and a conventional conservative plaster cast treatment, a category of patient that, in the absence of particular occupational or sports needs for early functional recovery, despite having been informed of the possibility of faster healing times, when given the option of conservative therapy, does not agree to surgical treatment. In actual fact, scaphoid fractures are the most common consequences of minor injuries in a whole

Fig. 15.18 (**a**) A 17-year-old patient, student involved in high-level sport activity (Judo), who was referred 6 months after the injury with radiological signs of non-union of the proximal pole. (**b**) The MRI showed no avascular change in the proximal pole, a prognostic sign favorable for biophysical stimulation. (**c**) One month after dorsal fixation of the scaphoid bone, without bone grafting, the fracture was still visible. The patient was prescribed a wrist modular splint and Osteobit® for 40 days (splint to be worn continuously for 30 days, followed by 10 days' use with Osteobit® at night-time only). (**d**) The X-ray at 60 days showed that union had been achieved

Fig. 15.19 (**a**) A 24-year-old male, kickboxing practicing. Junctional nonunion, (**b**) with MR suggesting an avascular status of the proximal pole. (**c**) It is still possible a screw fixation through the volar approach only using a short leading thread screw, in association with a NVBG from distal radius. This radiological delay union (1 month after surgery) can be early treated with Osteobit® (for 2 months) in order to accelerate the bone healing while leaving the patient free to mobilize the wrist early anyway. (**d**) Radiological late result. (**e**, **f**) CBCT depicts bony union. Perhaps, in this case, the electric stimulation had an ally in a sort of "metaphyseal core decompression". This was my consideration observing this radiological and (**g**, **h**) clinical result at 3 months

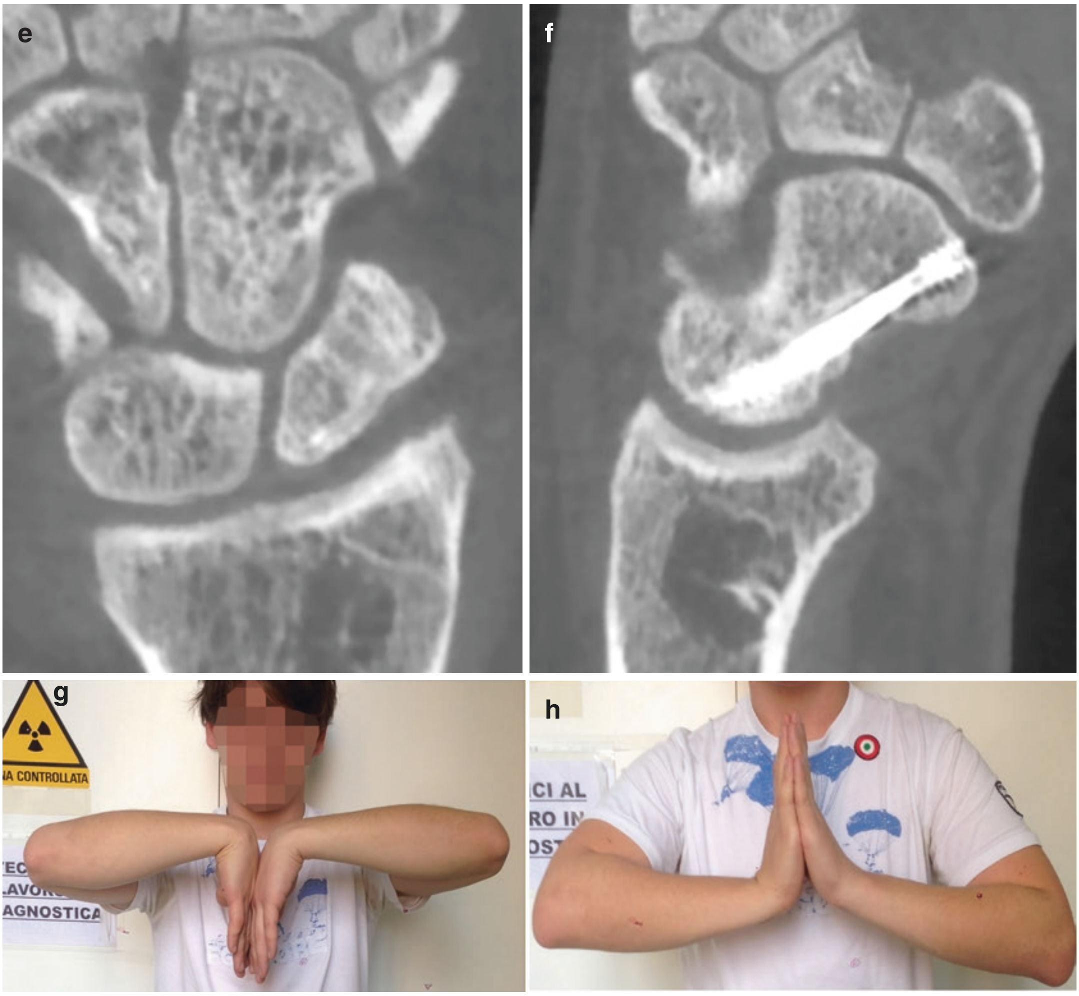


Fig. 15.19 (continued)

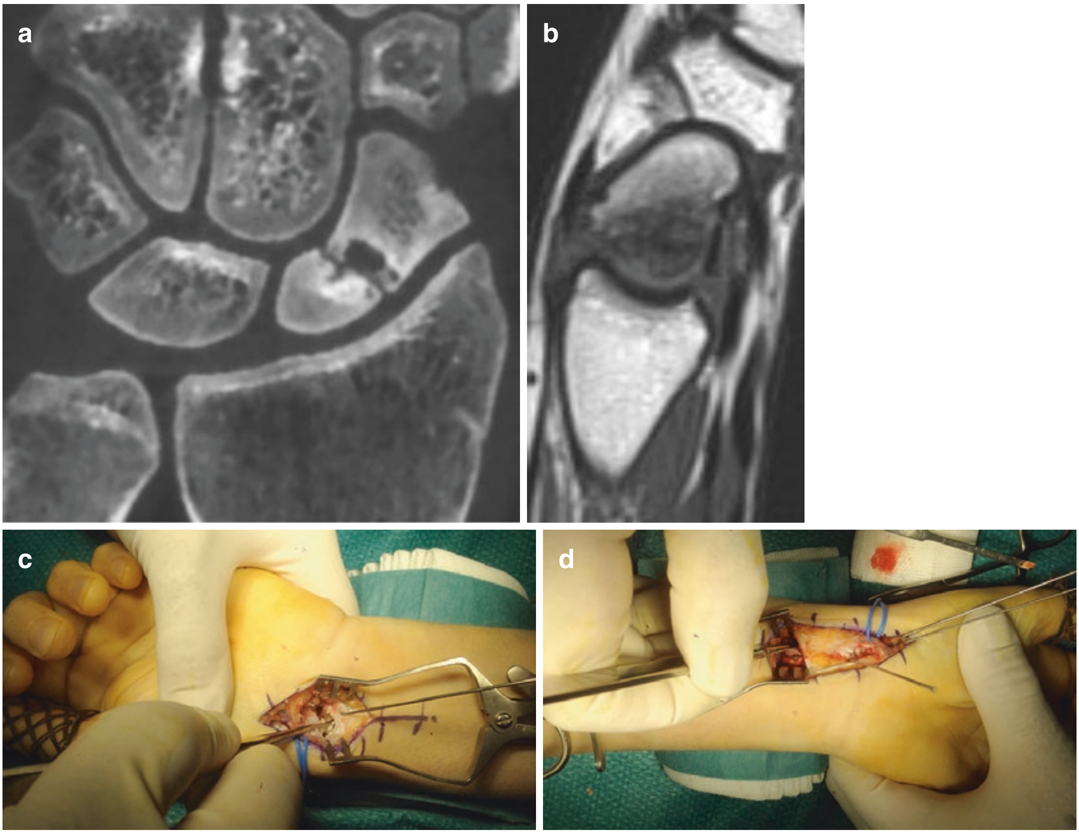


Fig. 15.20 (**a**) An 18-year-old, male, left wrist, not professional boxer. Proximal pole nonunion, (**b**) probably totally avascular, (**c**) at surgery, the pp and part of the distal fragment are completely sclerotic, and after debridement the pp is completely empty. (**d**) Spongious graft from radius was packed down into the cavities, and a structural CS graft from radius is inserted to fill a volar cortical "gap". (**e**) Two K wires are used for internal fixation. Extremities are bent around the tuberosity checking intraop that there is no impingement with FCR tendon. All anatomical structures are reconstructed: (**f**) RSC ligament, (**g**) the ST capsule, (**h**) the floor of the FCR sheath and (**i**) the superficialis fascia. In this way this mini-invasive surgery can be competitive with an arthroscopic bone graft, because the technical aspects of the procedure are the same. Osteobit® was used for 3 months after surgery. (**j**, **k**) At 3 years K wires are still inside the bone without limiting the wrist function and (**l**, **m**) the ROM. (**n**–**p**) Harvesting the graft from the radius activates a radius "core decompression" effect, that in combination with CCEF and a stable longstanding fixation, even by means of the most simple device, can obtain the bone healing even in an avascular PPN, demonstrating that NVBG may be an alternative to VBG

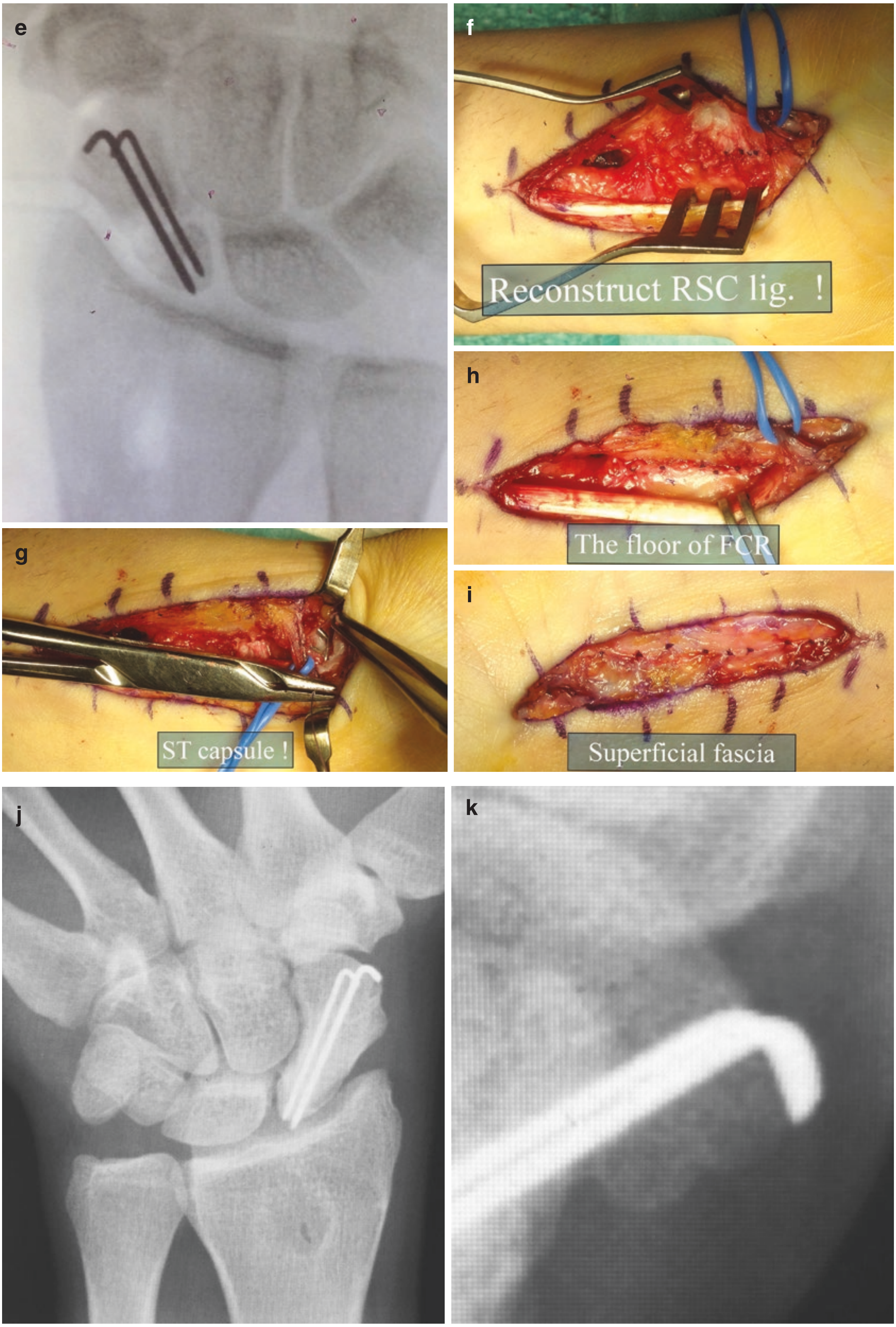


Fig. 15.20 (continued)

Fig. 15.20 (continued)

Fig. 15.21 (**a**, **b**) A 30-year-old male, right wrist, practicing not professional kickboxing, seen 1 year after trauma for persisting pain during sport activity, (**c**) with a MR imaging showing an obvious blood supply impairment of the proximal pole. No bleeding points were observed during the debridement of the pp. (**d**) A nonvascularized corticospongious graft from radius, two K wires and Osteobit® for 3 months produced the bone healing, even with a diffuse demineralization. (**e–h**) X-ray and CBCT late result. This patient used two kinds of different biophysical stimulation device (Biostim® and Osteobit®) in order to face also the diffuse demineralization, probably indicative of the hyperemia stimulated by the distal radius "core decompression". K wires, perfectly bended around the tuberosity, are still inside after 2 years (**i**, **j**) without any functional limitation

Fig. 15.21 (continued)

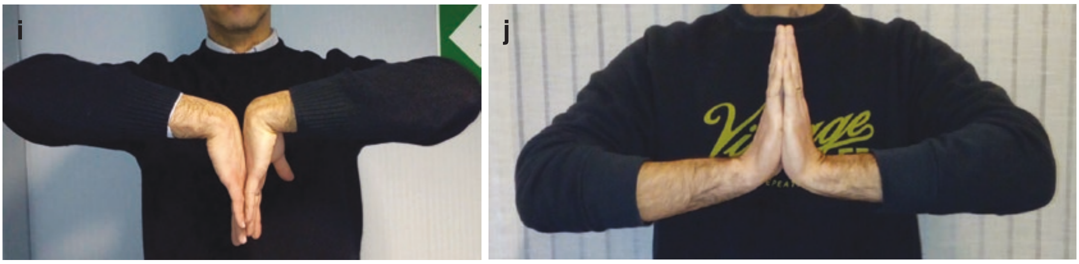


Fig. 15.21 (continued)

host of sports activities practiced by students, many of whom are under 18 years of age.

In this case, replacing the plaster cast with a "lighter" modular (a wrist module and a thumb module) splint that makes it possible to adequately immobilize the wrist and the thumb ray (with the interphalangeal joint free) and to combine, from the outset, conservative treatment and use of new-generation biophysical systems able to accelerate the union process would appear to be an option worth taking into consideration, even in older patients not involved in high-level sport activity (Figs. 15.12 and 15.13).

A significant number of patients are referred for a consultation 30–60 days after the injury, due either to a failure in identifying the fracture or to an effective delay in union following initial plaster cast treatment. As these patients, due to their functional needings, have already opted for conservative treatment, they are more likely to choose noninvasive treatment that nevertheless permits a certain degree of self-sufficiency (Figs. 15.14, 15.15 and 15.16).

There are particular conditions such as delayed union with increased radiological density in the proximal fragment, with comminuted or sagittal fracture of the proximal fragment in which a difficult and long bony union process can be foreseen (Fig. 15.17).

If, despite the consideration that the undeniable conditions of stability obtained with screw fixation, which can be confirmed directly on the operating table, the size of the proximal pole is such as to expect a delayed bone union, the simultaneous use of capacitive systems combined with a modular splint represents an aid to promote bone union. This aid can be taken into consideration immediately after surgery or when radiological signs of delayed union become apparent (Fig. 15.18).

In addition, certain conditions are associated with unfavorable prognostic factors, such as junctional nonunion [105] with a volar "gap" in the cortical wall, in which the partial hollowing of the proximal pole, even when packed with a nonvascularized or even vascularized cancellous or corticocancellous bone graft, creates such unfavorable biological conditions that even a screw or other fixation device is unable to modify. In these conditions, above all when using a NVBG, I believe it is reasonable to stimulate the osteogenesis process with a capacitive system applied after surgery, as soon as possible, in association with a splint (Figs. 15.19, 15.20 and 15.21).

Even more unfavorable conditions are created in failed fixations, in which it is essential to try to "save the scaphoid", often due to the young age of the patient. Screw removal generates conditions of stability and vitality that are so precarious in the proximal fragment that, whatever the treatment performed, even using new-generation fixation devices [139, 140] or a vascularized bone graft (VBG), combining a biophysical stimulation of osteogenesis that could facilitate an inevitably slow bone union, is an option to be considered (Figs. 15.22, 15.23, 15.24, 15.25 and 15.26). We have to remind that

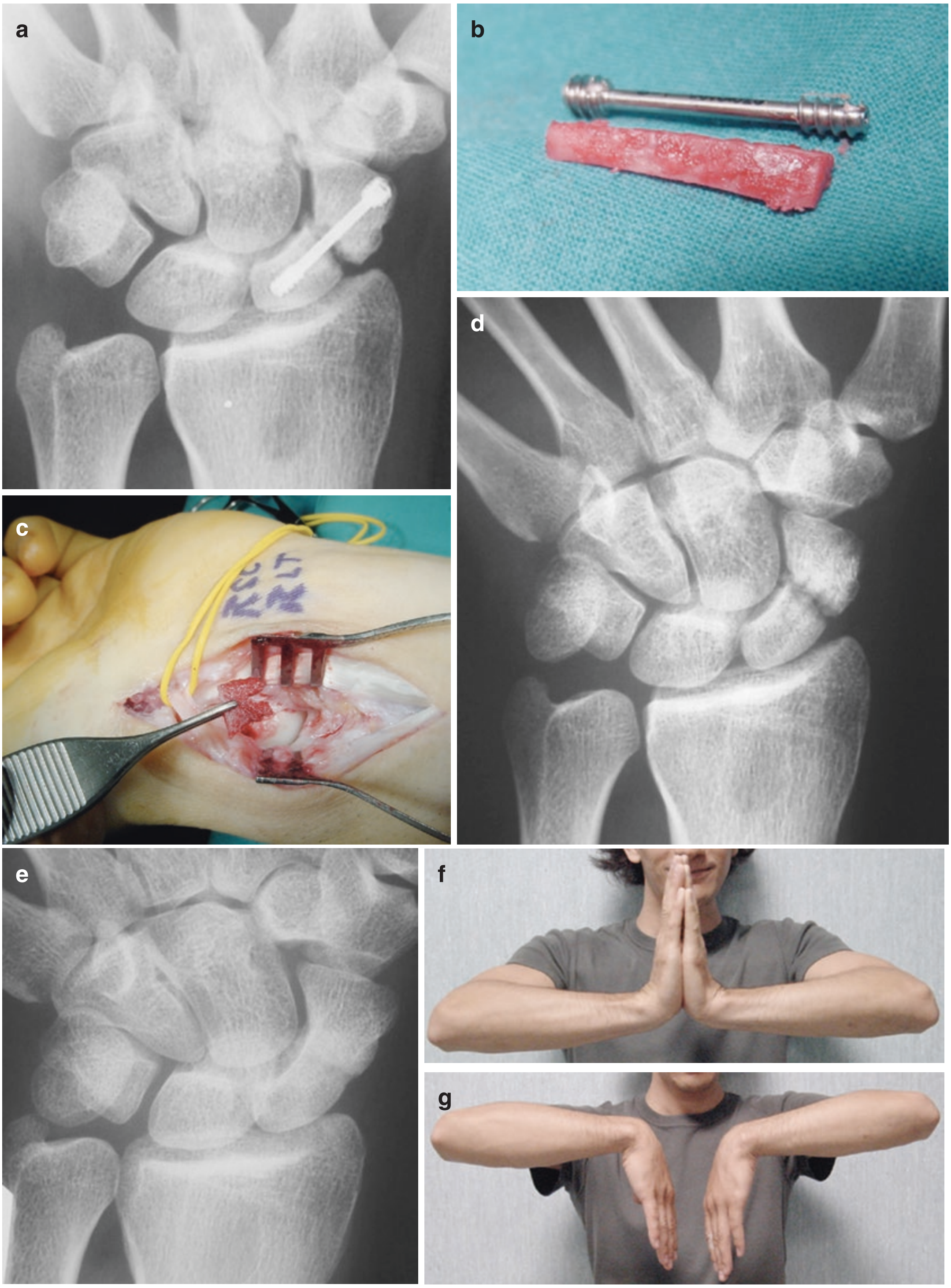


Fig. 15.22 (**a**) A 28-year-old cardio kickboxing instructor. Failed fixation with a screw applied with a correct axis. (**b**) Once the screw had been removed a peg graft, (**c**) and a "horse shoe" graft were harvested from iliac crest. The peg graft has to be a little oversized in relation to the screw, because it has to be inserted in a "press-fit" way, and later on the "horse shoe" graft will fill the usual volar gap, surrounding the peg graft. (**d**) The stability of fixation is verified directly at the operating table and permits an early mobilization and (**e**–**g**) good clinical and radiographic results. Combining capacitive stimulation during the first 4 weeks of treatment can be appropriate in speeding bone union

Fig. 15.23 (**a**) A 24-year-old man, right wrist, heavy manual worker. Failed nonunion fixation with a NVBG graft from distal radius. (**b**) Delay union after screw removal and "peg + horse shoe" graft from iliac crest. (**c**) Osteobit® has been used for 3 months

Fig. 15.24 (**a**) A 22-year-old male, right wrist, kickboxing, proximal pole nonunion treated with dorsal NVBG from radius and screw fixation. (**b**) At 6 months the failure of fixation was clear, and (**c**) a dorsal "peg + horse shoe" graft from the distal radius was performed. (**d**) At 2 months the nonunion was still evident. (**e**) Osteobit® was used in combination with a splint for 3 months. (**e**) Facing this radiological result one should argue about the possible "metaphyseal core decompression" effect on the bone healing

Fig. 15.24 (continued)

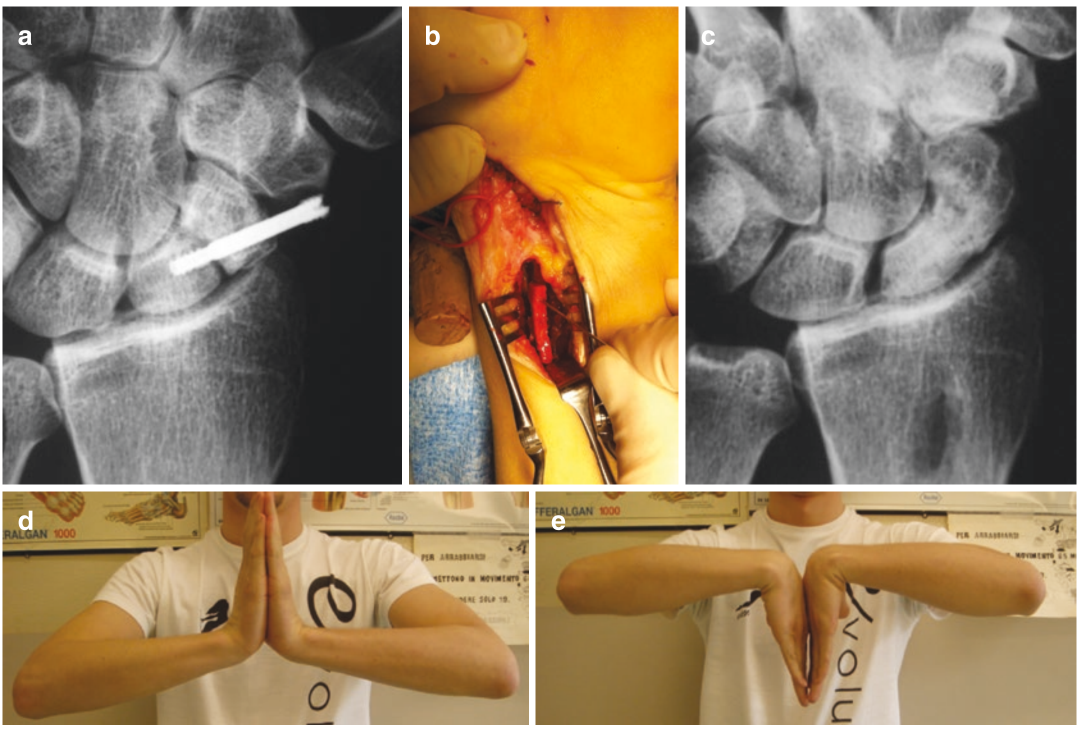
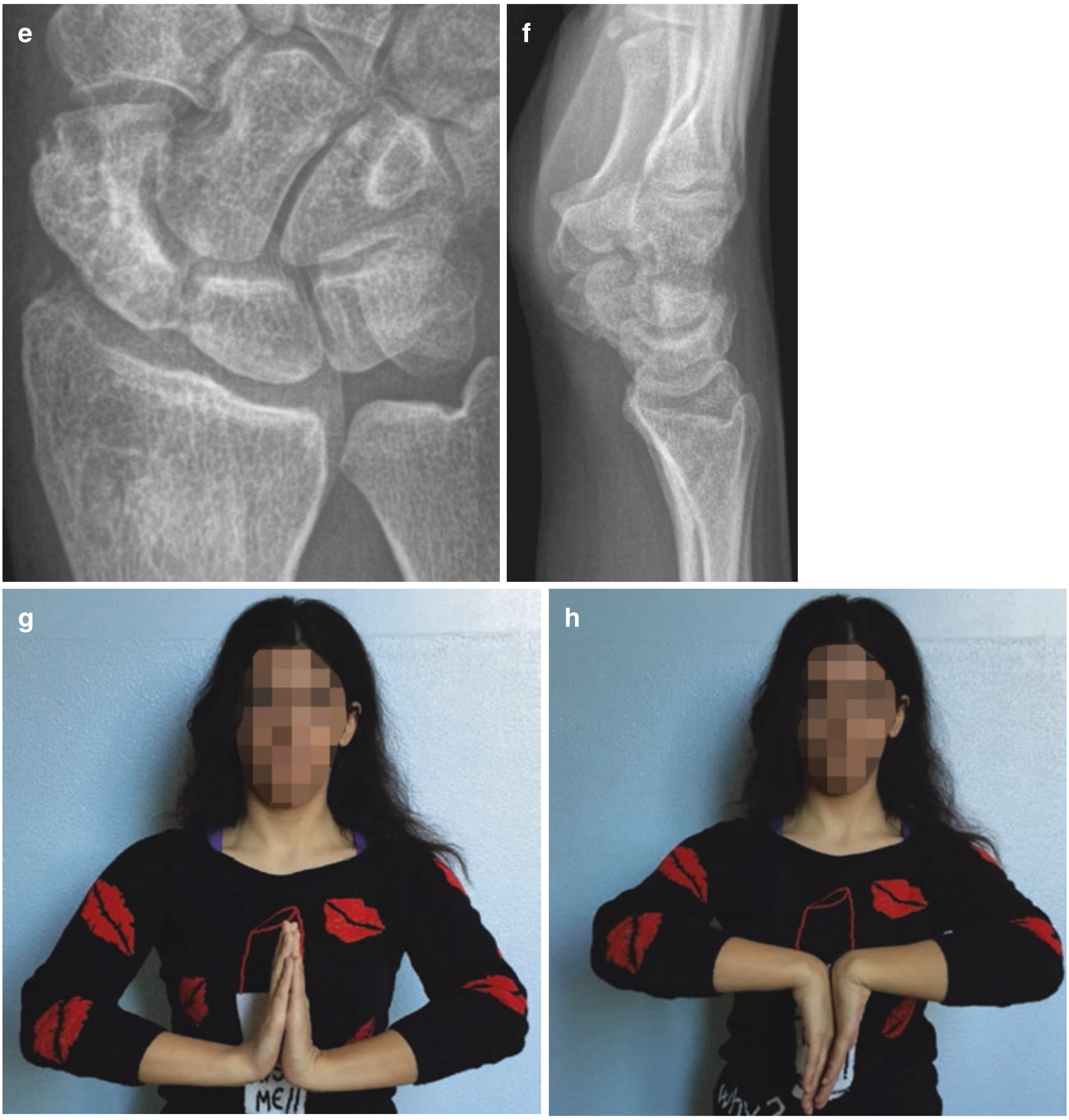


Fig. 15.25 (**a**) A 21-year-old man, right wrist in judoka. Failed fixation in a nonunion treated with a conventional interpositional iliac crest graft. (**b**) The "peg" graft can be harvested also from the distal radius together with the spongious graft that is needed to fill the volar gap at the nonunion site. (**c**) Radiological and (**d**, **e**) clinical result at 6 months. Osteobit® and the "radius core decompression" effect may have had a combined role in the bone healing

Fig. 15.26 (**a**, **b**) A 20-year-old, right wrist, woman, championship freestyle motocross. Failed fixation. Bone density suggests avascular proximal pole, confirmed at surgery, that is the main indication for a VBG. (**c**) A NVBG ("peg + horse shoe" graft) was harvested from distal radius, and two K wires, left in situ for 2 years, create such a stable fixation (**d**) to obtain the revascularization of the pp and (**e**, **f**) and the scaphoid morphology and intracarpal angles restoration as well, (**g**, **h**) in order to allow this young patient to go on with her favorite sport



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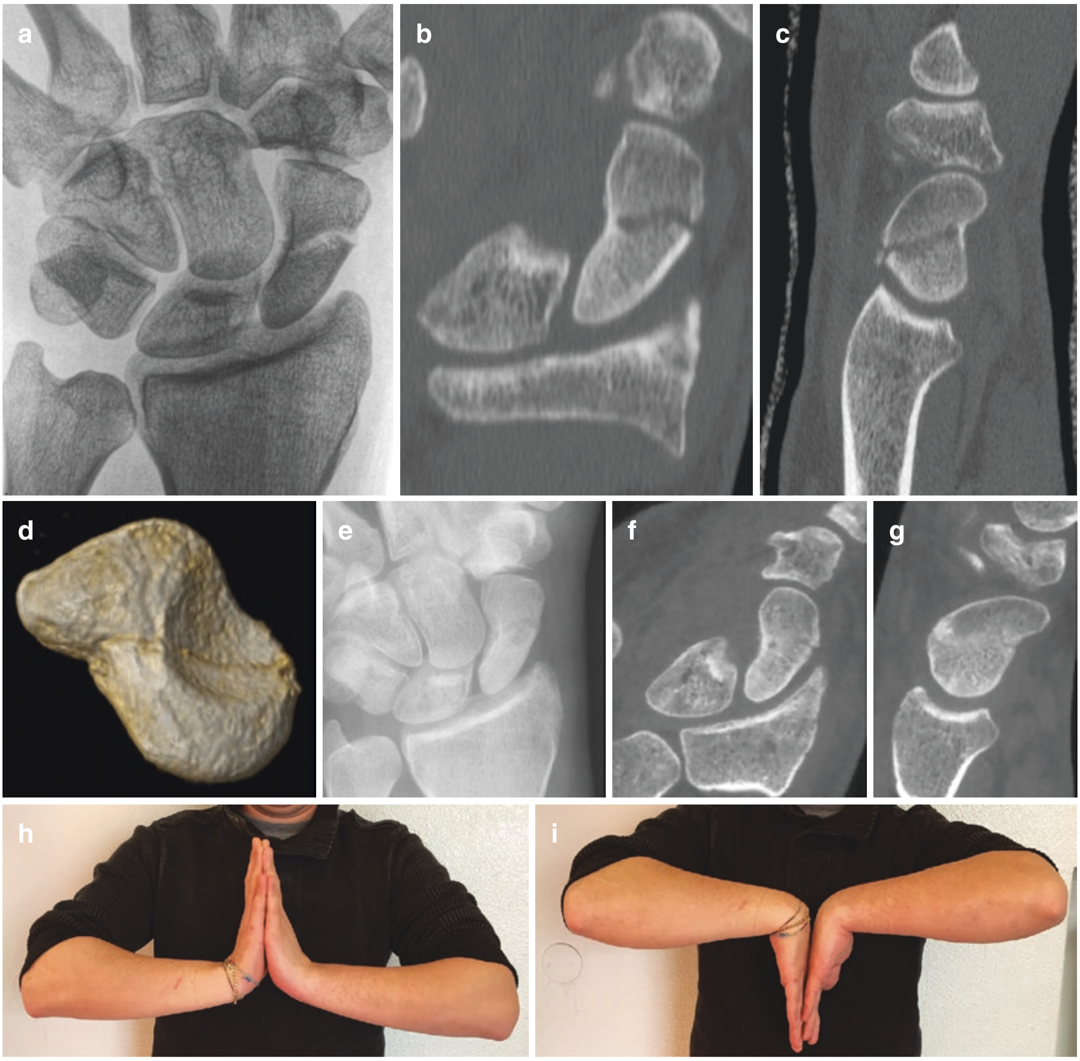

Fig. 15.27 (**a**) A 22-year-old student, right wrist, boxer, seen after 45 days of conservative treatment. (**b–d**) CBCT spatial orientation of fracture line in coronal and sagittal planes suggest that screw fixation could be difficult to perform both with volar retrograde both with dorsal anterograde technique, for the risk of fracture displacement during screw introduction. (**e**) X-ray after 1 month of conservative treatment with combined Osteobit® and splint (**f**, **g**) CBCT evolution of the bone healing after 20 days more of the same conservative treatment. The patient was allowed to interrupt immobilization twice during daytime to start sessions of active mobilization within the range of pain. (**h**, **i**) ROM at 2 months from the onset of the conservative treatment

these are the ideal conditions for fixing the scaphoid, as an alternative approach, with the specific miniplate for scaphoid reconstruction [139, 140].

15.15.3 Conclusions

I believe that the capacitive system, combined with conservative treatment by means of a splint, can be considered an alternative treatment option in the following cases:

- Undisplaced fractures when the patient (often a young student) refuses surgical treatment (mini-invasive open or percutaneous fixation) and when surgical treatment can be applied at a later time in the event of delayed union
- Delayed union in the presence of positive prognostic factors (on X-ray, CT, MRI) [216, 217] justifying biophysical stimulation of osteogenesis
- Undisplaced fractures, even in patients with high-level sport involvement, when screw fixation may be difficult to perform for the risk of complications such as fracture displacement during fixation (Fig. 15.27)

So also in athletes the treatment approach can be less aggressive!

- As an addition to surgical treatment in the presence of difficult or complicated nonunions (proximal 3rd and failed fixation) requiring vascularized (VBG) or nonvascularized (NVBG) bone grafting

Combined biophysical stimulator and splint therapy, when it was considered to be possible, proved to be perfectly compatible with daily activities and did not slow functional recovery. More specifically, in the treatment of fresh scaphoid fractures, where the indication for internal fixation has been further expanded with the percutaneous technique, conservative treatment is still an option for young patients, often student, who are not working and who do not practice sports on a competitive level, precisely because it can be combined, from the onset, with capacitive systems, by using new-generation modular splints. It goes without say that it is not possible to report the healing times for cases comparable to those presented, in which the same conservative or surgical treatment is performed without using capacitive systems, as it is practically impossible to find scaphoid bones with the same pattern of fracture or nonunion, location and spatial orientation, blood supply conditions in the proximal pole and time elapsed since the trauma; however, the ease of early use of new-generation capacitive systems, whose efficacy in the osteogenesis process is well supported by scientific evidence, obtained by the utilization of an easy-to-use modular splint, supports the use of a system that is suited to all those hand and wrist bone problems in which there is a delay in the osteogenesis process.

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16 Rehabilitation in the Athletes

Ilaria Saroglia and Giulia Pompili

16.1 Epidemiology

The introduction of martial arts in the 1990s coincided with an increase in hand and upper limb injuries. This seems to reflect the violent nature of current combat sports.

These sports can be classified in three categories: strike, grip, and mixed. Strike sports include boxing, kickboxing, karate, and taekwondo, whereas grip sports include Brazilian jiu-jitsu and judo. Mixed martial arts include those that combine grip and strike (fists and kicks) and aim to overcome the adversary. This third category records a 13% rate of hand injuries [1]; however, the most violent sport is boxing with 44% of upper limb injuries, 90% of which involve the hand and fingers [2].

In 2012, a survey on martial arts enthusiasts showed that 53% of upper limb injuries involved the hand and wrist [3]. Diesselhorst et al. studied 758 subjects, finding that the most frequent injuries were dislocation/subluxation (47%), followed by abrasions (26%). In 56% of cases, injury occurred during defense or attack and in 33% of cases during engagement with the adversary.

Gender differences are evident in martial arts injuries: men usually suffer injury to the wrist and hand and more often undergo surgery [3, 4] whereas women tend to suffer shoulder and elbow injuries.

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16.2 Sport and Injury

Rehabilitation of athletes is particular because the type of injury has both physical and psychological aspects [5]. Long periods of immobility can lead to life changes, since the athlete is forced to suspend habits (training, nutrition, rhythms, and mental hygiene). If protracted, separation from the sporting environment can lead to loss of social role and even social life through changes in self-image and self-esteem. This negative psychological condition makes functional recovery after trauma much slower [6]. Briefly, depending on contextual factors and personality, poor adaptation to injury can lead to anger, feelings of impotence, mood swings, guilt feelings, obsessive demand to return to "normal," irrational and depressive thoughts [7], "insecure" return to activity, and even early retirement from the sport in severe cases [8]. Injury and more generally pain are part of sport; however, while pain can have different meanings for an athlete (routine performance pain, physical pain announcing a state of form, or alarm pain suggesting an imminent lesion), a state of chronic pain syndrome and grief reaction (as for bereavement) may be reached, impairing normal personal function in the family, at work, at school, and in relationships.

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Pain can also be used positively in rehabilitation with associative and dissociative techniques. Dissociation is a cognitive strategy in which an injured athlete's attention can be directed away from the pain. Association is the opposite, in which an athlete focuses directly on the specific locus of pain and tries to frame it [5, 9].

16.3 General Concept of Rehabilitation in Athlete

Athletes are difficult to rehabilitate due to the strong psychological component that binds them to the injury. For rehabilitation, collaboration between doctor, psychologist, and trainer is essential, with family support or involvement [10]. Injured athletes go through four psychological phases: denial, anger, depression, and acceptance. The easiest to rehabilitate are those with inner motivation, social support, and high self-esteem. According to investment theory, athletes need to know the treatment protocol and the various objectives to achieve in order to believe in its efficacy and to set personal objectives [9].

Summing up, the rehabilitation protocol should be customized to the athlete's psychological and physical nature and the functional requirements of the sport in question.

16.3.1 Role of Psychologist

- Psychodiagnostic assessment of the patient's general nature, sport-specific traits, and emotional-cognitive response to injury and to rehabilitation.
- Psychological maintenance centered on mental flexibility is essential to overcome fear of being injured again on resuming activity.

16.3.2 Role of Therapist

- To understand the particular sport and the movements involved with the aid of memorized movement-optimizing mental guidelines.
- Proprioceptive training in keeping with the athlete's perceptual-cognitive style.
- The first phase is planning, where priorities are established, identifying the techniques and organizing a program; the program is conducted in combination with physical rehabilitation, first of all to combat the anxiety caused by suspension of sporting activity.
- Schmidt [11], Harris [12], and Jowdy [13] described the Carpenter effect or an increase in muscle activity due to mental repetition of a movement with the subject at rest (imagery). There is electrodiagnostic evidence that imagining a well-known motor activity elicits neuromotor activation.
- The athlete is stimulated by the feedback of goals achieved during rehabilitation, e.g., isokinetic testing [14].
- Ideomotor training in which known athletic movements are practiced.
- Return to sporting activity is planned with the doctor and surgeon.

16.3.3 Role of Athlete

- Positive thinking by clearing the mind of anxiety and the fear of being unable to regain previous form
- Accepting recovery times without forcing or unrealistic plans. Seeking the best recovery possibilities by active rehabilitation, for example, using mental training with imagery (mental repetition or "reliving" a movement or scenario) and cognitive pain control strategies
- Focusing attention on the present rather than the past, reflecting on one's capacity and ability to rehabilitate (role of self-effectiveness)
- Thinking about future activity, overcoming the frustration occasioned by inactivity
- Eliciting support of friends and relatives (this has positive psychological effects and helps the subject to cope with the negative event)
- Accepting the condition of being injured

16.3.4 Role of Trainer

- Realistic goal setting [15]: replanning of competitive aspects on return to activity in order to avoid immediate disappointment and unmanageable anxiety associated with expectations that are overambitious with respect to the athlete's current physical and psychological status
- Teaching self-talk techniques involving inner dialogue aimed at behavioral self-control: use of stimulus words aimed at optimizing a technical movement and at self-effectiveness, e.g., I will throw in that direction, I am strong.

16.3.5 Summing Up

- Athletes are delicate patients.
- Care of injured athletes requires an overall approach (trainer, sports medical specialist, psychologist, family).
- Resumption of activity can be accelerated with the use of protection (splints, taping, bandaging) without forcing tissue healing times.
- The motor scheme is replanned.
- Care provides security and overcomes trauma.
- The athlete is returned to his sport.

16.4 Care of Injured Athletes

The care of injured athletes begins with detailed assessment of the type of injury, its degree, the patient's personality, age, dominant limb, and sport. These aspects are essential for determining specific, personalized, conservative, and postsurgical treatment. Splints and taping are valid auxiliaries for protecting and rehabilitating patients. The timing of rehabilitation depends on the biological stages of healing. In this section, we consider the stages of tissue healing after surgery: the inflammatory, relative tissue fragility, and relative tissue strength [16] stages. We also discuss about rehabilitation concepts applicable both for conservative and post-operative management. These are in particular: the rehabilitative imagery, the latest proprioception studies by E. Hager, more briefly the neurosensory rehabilitation proposed by B. Rosen, and finally the use of plyometric techniques, hitherto exclusive to trainers and coaches but now included in the final phase of rehabilitation in which we retrain sport-specific athletic movements enabling the athlete to return to the world of sport. The whole rehabilitative program must be designed and conducted with a team composed of doctor/surgeon, physiotherapist, psychologist, trainer, and family. Stages of tissue repair:

16.4.1 Stage I: Inflammatory Stage (up to 45 Days After Surgery)

Care begins immediately after surgery. The objectives are treatment of swelling and pain, correct positioning of the unloaded limb, and protected tissue gliding.

- PRICE (protection, rest, ice, compression, elevation)
- Lymph drainage
- Scar treatment
- Vibration
- Early motion protocol

16.4.1.1 Protection/Rest

The first approach to an injured hand and wrist is unloaded splinting. This depends on the type of injury, but generally the wrist should be slightly extended or at 0°, with slight ulnar deviation and neutral prono-supination to facilitate tendon gliding and therefore reduce swelling. Wrist flexion must always be avoided because it tenses the extensor tendons, while tenodesis makes the fingers and metacarpophalangeal (MCP) joints stretch automatically, and with time the arches of the hand become inverted. An incorrect splinting position can increase swelling and pain and cause wrong tensions in injured tissues and even complex regional pain syndrome (CRPS) [1].

16.4.1.2 Ice, Compression, and Elevation

During the inflammatory stage, the reduction of swelling and pain is our primary objectives. Lessening edema and correct splinting generally lead to a reduction in pain. Inflammatory swelling is a biological response to trauma and surgery. Edema accumulates in the interstitial spaces, limiting joint movement and decreasing tissue nutrient supply. In the tissue repair stage, edema causes collagen shortening: the greater the edema and the longer it persists, the more extensive the scarring and the resulting pain, adhesions, disfigurement, and disability [17]. Edema is treated [18] by active range of motion (AROM) gliding, ice, elevation above heart level and compressive cohesive elastic bandaging [19]. Patients are instructed to raise the arm every hour and perform a series of exercises that promote tendon gliding: hook, fist, and straight fist [20]. An arm sling is not recommended because it causes elbow-shoulder radiation.

16.4.1.3 Manual Lymph Drainage [21]

Simple lymphatic drainage concepts can be applied to local edema to mobilize tissue fluid and increase lymphatic flow.

16.4.1.4 Scar Treatment [22–24]

– *Inflammatory stage (3–6 days)*: Scar management should start from the first wounding day. In this first stage is crucial to avoid infections. Thus, is recommending to control the variables that could lead to this complication, an excessive inflammatory state, or a dehydrated wound.
– *Fibroblastic stage (day 5 to week 6)*: fibroblasts synthesize collagen and the scar is raised and red. Treatment begins when any stitches are removed. The techniques are manual massage and contact ultrasound with a 3 MHz probe or in water with 1 MHz that help soften the tissues by defibrosis. Since collagen fibers randomly restructure against normal orientation, in order to discourage tissue adhesions, we work on tissue lengthening and gliding with taping to elicit multiplane gliding [25–27] (Fig. 16.1), vibration, and silicone gel compression [28–30]. As of week 3, the scar acquires 20% of its final elasticity. If the scar is hypersensitive, desensitizing treatment is recommended (Fig. 16.2).

Fig. 16.1 Scar treatment with taping

Fig. 16.2 Scar desensitization

16.4.1.5 Vibration

Some authors sustain the importance of vibration, applied through a window in the plaster or splint during the period of immobilization, to maintain an illusion of movement. According to Naito [31] "vibration stimuli of 80 Hz applied to the tendons of muscles can elicit illusory movements by stimulating the muscle spindle afferents." Studies have shown that vibration of a unilateral wrist extensor tendon activates unilateral and contralateral motor-related areas [16].

Dynamic proprioceptive inputs through muscle vibration in an immobilized arm can prevent hemispheric imbalance, while proprioceptive inputs from the hand increase inhibition of the muscles of the opposite hand [32, 33].

16.4.1.6 Transcutaneous Electrical Nerve Stimulation (TENS)

This technique is useful for stimulating endorphin production to ease pain. M. Boutan proposes using muscle stimulation for drainage by placing an electrode on the back of the hand and another posterior to the shoulder [34].

16.4.1.7 Mobilization

In this protective stage we can train the athlete with ideomotor imagery and mental exercises to maintain muscle activation without movement. Isometric exercise is begun in cases in which the early protected mobilization protocol allows it.

16.4.2 Stage II: Relative Tissue Fragility (45 Days to 3 Months)

In this stage, edema and the scar continue to be treated, using specific protocols according to the type of injury and surgery.

- Electrotherapy
- Control of edema
- Scar treatment
- Mobilization
- Splinting

16.4.2.1 Electrostimulation of Muscle

It prevents atrophy, while complementary adaptation mechanisms stimulate muscle plasticity. Muscle stimulation can also be used in the early stages of rehabilitation as it is "active" exercise that stimulates motor unit recruitment. It can also be used in association with voluntary isometric contraction. Muscle stimulation (monopolar, bipolar, or interferential) is indicated to maintain tissue gliding and increase the range of movement when voluntary stimulation is unable to do so. Electrostimulation must observe postsurgical tissue repair timing. In cases of tenolysis, it may begin immediately; in cases of tendon suture, after 6 weeks; and in cases of fractures of the wrist stably reduced with plates and screws, stimulation of the extensor muscles can begin early, whereas for flexor tendons it is necessary to wait 3 weeks: in other words, when the tissue is healing and contraction does not damage structures involved in repair [35].

16.4.2.2 Edema and Scar Treatment

It is a subacute chronic postsurgical stage in which the patient is taught manual edema mobilization (MEM) techniques and exercises that can be practiced at home [36, 37]: it is a method of edema reduction based on activation of the lymphatic system, involving diaphragm breathing, light skin-traction massage, exercise, pump point stimulation, and all in a self-management program (Fig. 16.3). The scar is in remodeling stage (up to 1 or 2 years), which is the period in which to treat the scar and obtain effective improvement of tissue gliding. Scar tissue gliding concentrates on all planes. If keloids form, silicone films [38] are applied day and night to decrease oxygen supply and keep the scar moist.

16.4.2.3 Mobilization

In this stage, the objectives are to restore joint amplitude and begin AROM exercises while observing the repair times of injured tissue. Active flexion of the fingers against resistance must be avoided until the soft tissues have cicatrized. The time necessary for complete bone consolidation ranges from 8 to 16 weeks; if the bone was reduced by compression with screws,

Fig. 16.3 Edema treatment with tape and self-adherent compressive bandage

the time is shorter [16]. Light activities of daily living (ADL) are allowed. For wrist injuries, maximum resistance and muscle strengthening are generally not allowed for up to 8 weeks. Cortical repair of the wrist is very important and begins with mobilization of the fingers by extension and flexion. Rehabilitative imagery is used, and much work is done on wrist proprioception. Electrostimulation combined with active exercise (e.g., radial extension of the wrist) (Fig. 16.4) has a cortical proprioceptive effect. Active exercise is mainly isometric with static contraction [39]. Mobilization, preferably active, only begins after the tissues have been prepared for gliding, namely, after softening by means of a paraffin bath or massage. Thermal agents rely on several methods of heat transfer to alter the temperature of the target tissue (hot packs or paraffin) [39]. The Canadian board is useful for active analytical movements and for teaching passive self-posture that the patient maintains for several seconds according to the "hold and relax" method of proprioceptive neuromuscular facilitation (PNF) (Fig. 16.5). Mobilization must be in physiological planes and in the directions described by dart-throwing motion (DTM) [40, 41]: from 40° of extension and 20° of radial deviation to 0° of flexion and 20° of ulnar deviation, using the midcarpal (MC) joint (Fig. 16.6) [42].

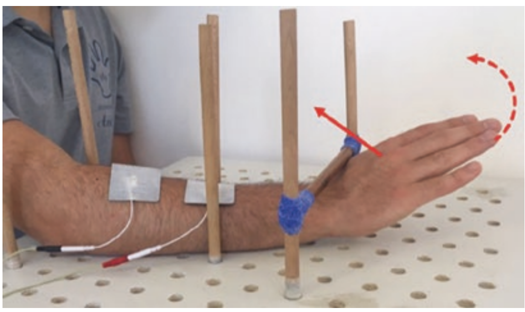

Fig. 16.4 Example of electrostimulation combined with active exercise

Fig. 16.5 Hold and relax exercise with Canadian board

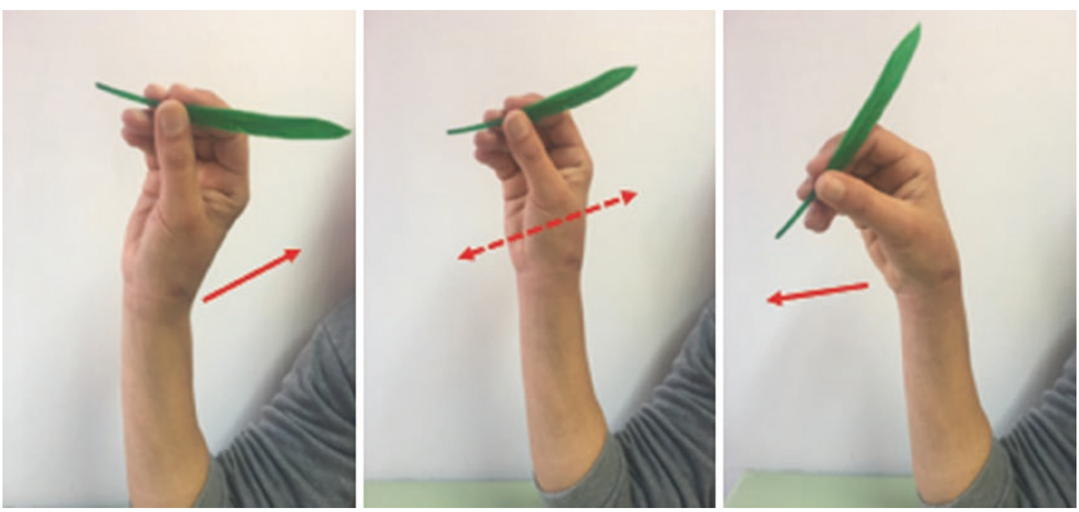

Fig. 16.6 Example of DTM exercise

16.4.2.4 Splinting

The patient is gradually weaned from the splint, which is still worn at night and during moderate and strong ADL. Protective splints can be made to help the athlete return to activity. Splints help to increase joint compliance in this phase and may be static progressive or dynamic to increase movement (Figs. 16.7 and 16.8).

16.4.3 Stage III: Relative Tissue Strength (After 3 Months)

In this stage, we work with the athlete to obtain mobility, stability, and proprioception (that latter is dealt with in a separate section). This is the stage of muscle strengthening and true proprioceptive stabilization. If the tissues have healed, if AROM and passive range of motion (PROM) have been completely restored, and if the type of surgery permits, work centers on muscle strengthening exercises, rhythmic and dynamic techniques of wrist stabilization, and plyometric (see separate section) aimed at recovering athletic movements.

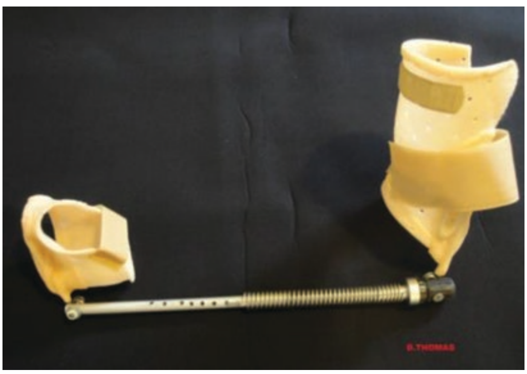

Fig. 16.7 Prono-supination splint, by gracious permission of Dominique Thomas

Fig. 16.8 Prono-supination splint, by gracious permission of Dominique Thomas

Objectives:

- Muscle strengthening
- Static muscle strengthening
- Dynamic muscle strengthening

16.4.3.1 Muscle Strengthening [26]

Exercises must follow protocols that progressively load the injured structures, starting with static and moving toward dynamic, and from analytical to global techniques, and taking muscle characteristics and the organization of myoaponeurotic chains into consideration. Amyotrophy caused by long immobilization manifests as loss of volume, affecting slow muscles more than fast ones. The most affected muscles of the hand are the intrinsic muscles. As we have already seen, exercises proposed in the fragile tissue stage are largely isometric. In this new stage, we use concentric dynamic contraction to improve neuromuscular rhythm and coordination, but since it is not possible to control the contraction well, we prefer eccentric dynamic contraction: it is the most physiological and stretches the muscle insertions as well as the muscle itself. Static training is generally indicated for largely tonic muscles (flexor carpi ulnaris, FCU; abductor pollicis, AP), whereas dynamic training concentrates on largely phasic muscles (extensor digitorum communis, EDC; extensor carpal radialis longus, ECRL; flexor carpi radialis, FCR; abductor digiti minimi, ADM).

16.4.3.2 Static Muscle Strengthening

It is always used at the start of a strengthening protocol, beginning with 20% muscle stretching, followed by activation of co-contraction of antagonist muscles; these contractions protect the bone and the joint. Static muscle strengthening can be manual (the physiotherapist personally controls the contraction parameters) or with elastic resistance. Intensity and resistance are submaximal. Three to five contractions are performed, holding them for 3–6 seconds per exercise. Rest time is double the working time. Static contraction exercises are alternated with muscle relaxation maneuvers. Muscle recruitment can be proximo-distal or disto-proximal with chains in series or in parallel.

16.4.3.3 Dynamic Muscle Strengthening

It occurs by rhythmic stabilization according to PNF techniques that associate proprioceptive reeducation and muscle strengthening. The exercises are performed with progressive resistance in flexion and extension, radioulnar inclination, and prono-supination.

In the final stage of rehabilitation and especially in athletes, it is essential that strengthening involves the entire upper limb. Then it is time for plyometric exercise (see separate section) to define athletic movements and optimize athletic performance.

16.5 Imagery

Imagery is a complementary rehabilitation technique that exploits brain plasticity and the reversibility of brain changes. In athletes, motor imagery involves breaking down sporting movements into many frames without associated body movement [43]. The athletes who rehabilitate most successfully are those who have already been injured and "evolved athletes" or those whose training of sporting movements included endless repetition. Delaquaize [31] and Priganc [44] proposed exercise based on the studies of Moseley [45], divided into three steps:

1. *Recognition of laterality* activating the premotor cortex and the supplementary motor area. Patients have to recognize whether the right or left hand is used in a figure they are shown without moving their hands or head (Fig. 16.9).
2. *Imagined movement* that activates the premotor cortex as well as the primary sensory and motor cortex. This exercise exploits motor imagery [46] of the sporting movement and is well known to athletes because it is part of their athletic training. Motor imagery activates the neurovegetative system [47]. Capacity for imagery is variable and subjective. There is "first-person" imagery where the subject experiences mentally a movement performed mentally and "third-person" imagery where the athlete relives a movement performed by others (he can be shown the sequences of his team mates training) [48]. In this way, he activates motor units in the brain without actually moving.
3. *Mirror therapy* exploits observation of the movement in a mirror. By watching the healthy hand reflected in a mirror, the patient stimulates the normal visual afferents of the injured limb [49]. This technique acts on the motor control system, informing the brain that the injured limb is moving correctly. It exploits visual feedback and motor command. Mirror therapy makes it possible to correct a wrong or pathological motor scheme and to find a cortical representation of the movement appropriate for the movement. Mirror therapy is highly indicated for reducing pain [50].

Fig. 16.9 Example of figures used for recognition of laterality

16.6 Sensory Relearning After Complete Peripheral Nerve Injury

Complete peripheral nerve injury causes an immediate change in the somatosensory and motor areas of the brain, causing neuronal connections to reorganize. If initially they managed signals to and from the interrupted nerve, now they reinforce other functions [51]. With time the nerve tends to regenerate, but its capacity to capture and discriminate information is radically different and impeded.

The rehabilitation method developed by Rosen in 2016 [52] is modeled on early sensory reeducation after total lesion of the nerve and specifically organizes the therapeutic approach on the basis of clinical recovery of capacities. We underline two stages: the first, lasting 3–4 months, is characterized by total absence of perception of the limb and is therefore the stage in which it is necessary to keep the corresponding brain areas active. In the second stage, skin receptors begin to capture the first information from their environment, and true sensory rehabilitation can begin.

First it is important to increase patient and caregiver compliance to this treatment by explaining the whole biological process of transformation that is occurring in the body, the consequences and possible complications, as well as the importance of continually stimulating brain plasticity by constant specific physical and mental training.

Stage 1 Imagery: The athlete has to imagine (with closed eyes) a pleasant past tactile experience, e.g., stroking a dog, taking a handful of sand, and touching the bark of a tree. If the patient has trouble with the exercise, images can be used.

- *Observation:*
  1. Touching different nonsensitive areas of the hand while watching action. This can be done by the contralateral hand, or the therapist can touch the same area of both hands with the same intensity.
  2. Observing someone who is touching different things and imagine the sensations.
  3. Mirror visual feedback (MVF).
- *Sense substitution exercises*:
  1. During activity, areas of the brain interact continuously with the various senses. Encouraging patients to exploit all senses while performing an action therefore stimulates and reinforces tactile sensitivity. For example, patients can be asked to pay attention not only to the taste but also to the color, form, and aroma of something they are eating.
  2. The Sensory Glove System has also proven to give good results.

Stage 2 Exercises with sensory and motor involvement are highly recommended. In some cases, local anesthetic, such as EMLA cream, can be used on the anterior forearm to draw attention to the cortical neurons of the forearm of the affected hand [53].

- *Localization exercises*: the skin of the hand is stimulated, and the patient has to localize the point of contact.
- *Identification exercises*: when ability to localize touch has improved, the patient can begin to explore various familiar or daily objects with different shapes, sizes, and materials. For example, patients can be asked to recognize a specific key in the bunch of keys in their pocket.

16.7 Proprioception

Also known as kinesthesia, proprioception is the capacity to perceive and recognize the position of one's body in space and the state of contraction of one's muscles, even without the help of vision. It is a fundamental part of the complex mechanism controlling eye-hand movements.

Wrist proprioception depends on afferent signals from mechanoreceptors (terminal sensory organs) in the joint capsules and ligaments. Afferent signals elicit spinal reflexes for immediate joint stability. Under normal conditions, tendon and joint capsule receptors exercise proprioceptive control on the joint; under pathological conditions, ligament injury or insufficiency may distort proprioception, disrupt the function of the reflex mechanism, and adversely affect dynamic joint stability [54].

Neuromuscular control of the wrist has clinical applications in carpal instability [55]. Proprioceptive deficit causes control instability and difficulty/uncertainty in performing hand and wrist movements, as well as in grip and stabilization. Proprioceptive feedback is important for organizing the upper limb in space [56].

In the literature, we find many papers on ankle, knee, and shoulder receptors. The latest studies by Hagert et al. [55] have shown the importance of proprioception in the rehabilitation of unstable wrists. The main requisite for wrist and hand proprioception after trauma or surgery is neuromuscular recovery. The exercise must be prevalently eccentric, exploiting antagonist muscles. Hager proposes a co-activation exercise with wrist extensors and flexors: in a balance exercise, both or single hands are placed on a ball (Fig. 16.10). Slow controlled movement of the ball on a table allows the patient to practice flexion and extension simultaneously and to produce balanced wrist movement. A maximal eccentric exercise of the wrist extensor muscles improves wrist stability and elicits greater co-activation of the wrist flexor muscles [57].

In the early stage of rehabilitation, isometric exercise of flexor and extensor muscles "strengthens" and stabilizes the wrist. It enables a predetermined protected range of motion without the risk of moving the joint too much [58]. Zhou [59] showed that "cross education" contralateral stimulation causes strengthening by exploiting the same muscles in the contralateral limb, probably through adaptation of the nervous system in the spinal cord. If immobilization after injury is protracted, there is loss of proprioception; by contrast, short immobilization is associated with increased brain plasticity of the contralateral motor cortex [49]. Avanzino et al. [32] proposed using 80 Hz vibration to stimulate tendons and muscles proprioceptively during immobilization of the arm, and this effectively maintained activation during short-term immobilization. In 2012, Guerraz et al. [60] suggested combining proprioceptive stimulation with viewing in a mirror and found that the kinesthetic result depended on the patient's preferred sensory channel. Since pain inhibits the proprioceptive system, it must be treated from the first sessions and reduced as early as possible [61]. Prolonged use of cryotherapy, effective in reducing swelling and pain in the initial stage, remains controversial if applied before proprioceptive exercise because it seems to decrease recognition of the joint in space [62].

Fig. 16.10 Co-activation exercise with one hand: neuromuscular conscious

16.7.1 Proprioceptive Exercise

- Proprioception is stimulated by handling objects, also in a bimanual task, in which the dominant hand is used for visual guidance and fine dexterity [63] (Fig. 16.11).
- Powerball (Fig. 16.12) is a gyroscopic exercise tool used in hand therapy to increase muscle endurance. It can be used for conscious and unconscious proprioceptive reeducation by reflex activation of the wrist muscles and unconscious activation of agonist and antagonist muscles [64].
- DTM can be used to stimulate wrist proprioception [65].
- Muscle electrostimulation is a strong proprioceptive stimulus [16, 35, 56].
- PNF pattern is another proprioceptive reeducation method.
- Manual traction of joint surfaces to facilitate joint motion, manual approximation of joint surfaces to facilitate co-contraction or postural holding, and manual therapy, especially Maitland's method, are proprioceptive methods.

Hagert [66] proposed a proprioceptive rehabilitation program for unstable wrist joints:

Stage 1—Basic hand rehabilitation
Stage 2—Proprioception awareness (mirror therapy)
Stage 3—Joint position sense (blinded passive and active reproduction of joint angle)
Stage 4—Kinesthesia (with exercise machine or manual passive motion)

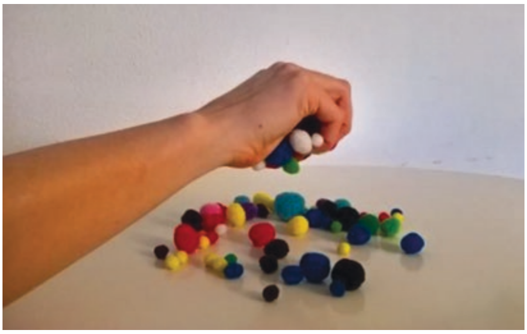

Fig. 16.11 Examples of proprioceptive exercises

Fig. 16.12 Exercise with powerball: unconscious neuromuscular activation

Stage 5—Neuromuscular conscious (isometric, eccentric, isokinetic, co-activation) (Fig. 16.13)
Stage 6—Neuromuscular unconscious (powerball exercise, plyometric training)

16.8 Plyometrics

Plyometrics from the Greek *pleos* (many) and *metros* (measure), is a physical activity characterized by a rapid eccentric contraction followed immediately by a concentric contraction of the same muscle. The term was introduced by Fred Wilt, an American athlete and trainer, to define exercises hitherto known as "jump training." It generally begins with an eccentric movement and concludes with a concentric one. For example, to throw a ball I begin with extension of the wrist (eccentric) and conclude with a concentric contraction when I release the ball [67, 68].

Plyometric exercise is actually more than this, also including three-phase stretch shortening cycles (SSC) [69]:

1. Eccentric pre-stretch: preactivation of the muscle before the eccentric phase
2. Concentric shortening phase and short rapid eccentric phase
3. Amortization phase (time to rebound): a fast passage between stretching (eccentric) and shortening (concentric)

Benefits of plyometric exercise are increased mean power and velocity, increased peak force and speed during acceleration, increased devel-

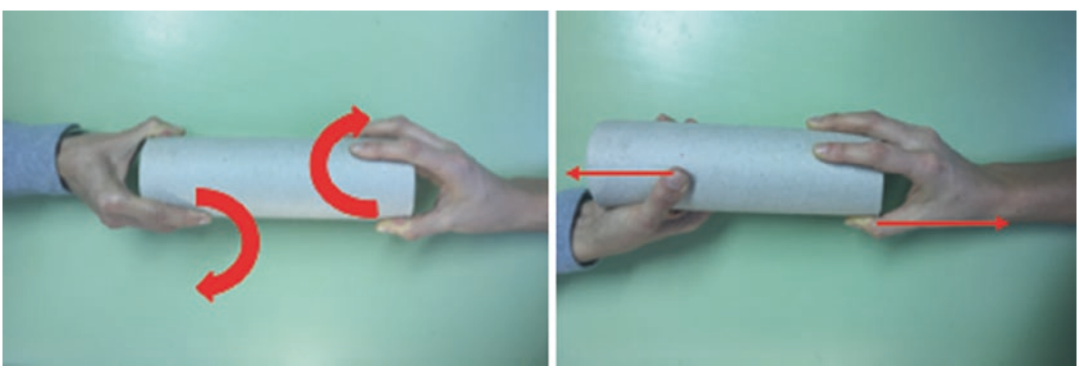

Fig. 16.13 Example of conscious neuromuscular exercises

opment of force over time, and accumulation of force and capacity to evoke and lengthen reflexes [70–72]. Specificity in plyometric training may include motions, angular velocities, loads, metabolic demands, etc. [73]. Lengthening and speed are needed to create force in sporting movements. Plyometric exercise works on this basis. The physiotherapist uses it to restore the athlete to high levels of technique and precision. Recently, plyometric methods have also been used by trainers and therapists to prevent injuries and to improve performance. Many authors have reported increased jump height, sprint time reduction, improved running economy, and improved joint position sense and postural control as a result of plyometric training (Fig. 16.11).

In conclusion, in martial arts and combat sports dynamic movements of the body in space, explosive bursts of force, and precise movements of the upper limb are required. Often rehabilitation exercises aimed at functional recovery do not have these characteristics. Plyometrics therefore fills this shortfall of rehabilitation toward sport-specific functional requirements [74] (Figs. 16.14 and 16.15).

16.9 Wrist Injuries in Combat Sports

> The stability and mobility of the wrist makes it possible to develop force in movements transmitted by the body to the hand and by the hand to the body. A stable wrist stabilises the hand in space and makes it strong. (D. Thomas)

Combat sports can cause a vast range of injuries. Many sports do not always involve physical contact, but overuse injuries may be encountered. Combat sports vary in technique, rules, and use of protection, and this affects the type and rate of injury. In certain sports, protection and padding is worn on the hands and forearms (e.g., boxing, taekwondo). This reduces the risk of hand injury [3] but has been associated with increased arm

Fig. 16.14 Example of plyometric exercise for the wrist: wrist extensor-flexor flips

Fig. 16.15 Example of plyometric exercise for upper limb: extension abduction one hand overhead

and shoulder injuries where protective equipment causes dissipation of proximal force. The risk of injury during martial arts has been observed to increase with years of participation, especially in athletes who practice these sports for more than 3 years [75]. This evidence is sustained by other studies showing that increasing levels of competition are associated with increasing recourse to surgery for hand and wrist injuries [4], The opposite trend is observed for karate [76]. Hand and wrist injuries in martial arts can affect nerves and vascularization or bones and ligaments. Here we consider the latter. Twisting and impact injuries are the main mechanisms of injury in these sports.

16.9.1 Prevention [77]

Kinetic studies (external forces applied to the wrist) enable us to evaluate the load that the wrist can sustain. It has been estimated that 80% of the load due to external forces with the wrist in neutral position is transmitted to the radiocarpal (RC) joint and 20% to the ulnocarpal (UC) joint; 45% is transmitted by the RC joint to the radioscaphoid (RS) joint and 38% to the radiolunate (RL) joint. External force is distributed through the MC joint to the scaphotrapezial (ST) joint (31%), scaphocapitate (SC) joint (19%), and triquetrohamate (TH) joint (21%) [78]. Depending on the sport and the techniques used, athletes sustain a considerable load on the wrists and hands.

Prevention has four main aspects:

- Taping/bandaging of hand or wrist (Fig. 16.16)
- Appropriate gloves/padding
- Improvement of strike technique (Fig. 16.17)
- Appropriate physical exercises

The objective of taping is to prevent forced abduction of the metacarpal heads during impact and to protect the MCP joint and the wrist. Bandaging is usually a combination of tape and padding with the same objective as taping. According to boxing rules, the tape should not be more than 1 yard long, and the taped hand must fit in the glove. There are three types of boxing

Fig. 16.16 Taping/bandaging of hand or wrist

Fig. 16.17 Training of strike technique

gloves: bag gloves used for training with the punching bag, sparring gloves for training, and competition gloves. The athlete should wear the correct gloves for what he is doing. The best strike technique suggests directing force toward the head of the third metacarpal bone. It is important to have the elbow and wrist aligned to ensure that the force is dissipated toward the second metacarpal bone, which together with the third constitutes a fixed unit of the hand. Wrong technique can lead to transmission of force to the fourth and fifth metacarpals that tend to fracture.

16.9.2 Distal Radius Fracture Management

Therapy techniques and activities are based on principles of fracture healing and fixation. Advances in surgical methods in the last 10 years have made early motion possible during rehabilitation of distal radius fractures. The goal of restoring range of motion (ROM) must be realistic [79], considering the type of fracture (intra-articular or extra-articular), and must make the wrist as stable and functional as possible. According to Ryu [80], the functional range of the wrist is 40° of extension, 40° of flexion, and 40° of ulnar-radial deviation. Athletes who have suffered high-impact injuries can have damage to soft tissues, the triangular fibrocartilage complex (TFCC), and the scapholunate (SL) or scaphotriquetral (ST) ligaments that slows down or changes the rehabilitation protocol and the final objective. The factors influencing the objective of total recovery of ROM of the wrist are the outcome of surgical reduction and restoration of anatomy. Nerve compression, tendon rupture, stiffness, and pain can reduce function and worsen final outcome. After surgical reduction, if there are no particular indications, the patient wears a wrist splint for 4 weeks [81] (Fig. 16.18).The splint leaves the long fingers and thumb free to allow gliding of the flexor and extensor tendons, so as not to lose the cortical motor image. Tissue gliding helps drain edema and, by the pumping effect of the flexor and extensor muscles, limits the formation of adhesions and prevents fibrosis and tissue retraction. The wrist should be immobilized in slightly extended position, with slight ulnar deviation and neutral prono-supination, never flexed. An incorrect position creates tension or compression of soft tissues, stagnation of fluids, and pain and may lead to CRPS.

16.9.2.1 Early Phase (1–6 Weeks) [82]

Goals: reduce edema and pain and promote tissue gliding.

- Scar treatment.
- Reduce edema by mobilizing the MCP, proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints, the elbow, and shoulder, combined with compressive elastic bandaging, ice, and retrograde massage.
- Tendon and soft tissue gliding.
- Muscle activation by imagery techniques.
- Light ADL.

Fig. 16.18 Wrist splint

16.9.2.2 Motion Phase

Begins once there is bone stability and may last up to 3 months; it follows tissue remodeling. If we encounter tissue stiffness in this wrist motion recovery phase, we include specific exercises in the rehabilitation program; for example, we use joint decoaptation in cases of capsular retraction. This method stimulates nutrient supply to the tissues and allows painless tissue lengthening [16].

Goal: to restore AROM and PROM of digits, elbow, and shoulder, AROM of wrist, and forearm rotation.

- Recovery of wrist extensors (without use of the fingers) has priority over recovery of flexion [81].
- Recovery of wrist extension must be done with the fingers closed because it is necessary to reestablish wrist movement dissociated from finger extension at cortical level [16]. Canadian board use ensures selected movement (Fig. 16.19). Active selective electrostimulation of the radial extensors of the carpals is useful to reevoke movement at cortical level and promote tissue gliding [39].
- ROM within functional limits.

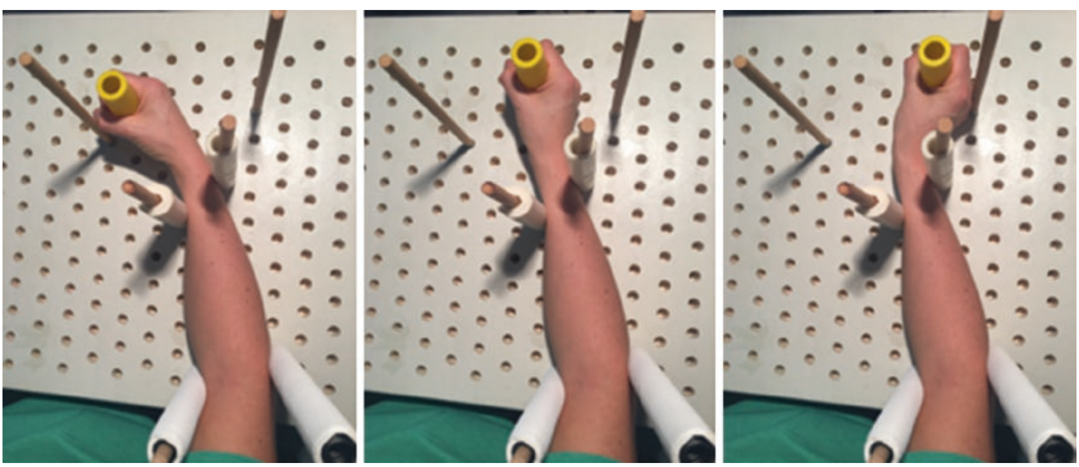

Fig. 16.19 Exercise for wrist extension on Canadian board

16.9.2.3 Function/Strength Phase (After 8 Weeks)

This phase generally begins after 8 weeks with the consent of the surgeon once the bone is repaired.

Goal: to progressively improve hand and wrist function and stability.

- Conscious and unconscious proprioceptive stabilization [66].
- Open kinetic chain exercises to stabilize the whole upper limb.
- Closed kinetic chain isometric progressing to isotonic exercises; resisted exercises with putty or grippers.
- General upper extremity conditioning and core strengthening exercises.
- Stabilization exercises including activities using a therapy ball.
- Grip and force tests [83, 84] can only be done after documented consolidation and not before weeks 6–8.
- Maximum effort is not allowed for 4–6 months.

16.9.2.4 Complications

- Tendon adhesions and scarring
- Median nerve compression/carpal tunnel syndrome
- Complex regional pain syndrome
- Tendonitis, tenosynovitis
- Ruptured extensor pollicis longus (EPL)/ flexor pollicis longus (FPL) tendons

16.9.3 Scaphoid Fractures [85]

For these fractures, it is important to warn the athlete about the long period of immobility required. Return to activity depends on the type of sport, involvement of the injured hand, and adapting a protective splint to the needs of the sporting movement [86]. Well-treated fractures in the body of the scaphoid heal in 3 months. Fractures in the proximal third of the scaphoid heal in 4 months. Fractures in the scaphoid tubercle heal in 6 months. Fractures in the distal third of the scaphoid heal in 2 months.

Noncompound fractures are treated with a thumb spica cast. Slight radial deviation and slight flexion reduce stress on the fracture and limit the possibility of dislocation.

- Fractures in the body or proximal pole of the scaphoid are subject to forces created by rotation of the forearm and are transmitted by obliquely orientated radiocarpal ligaments.
- Fractures in the distal third of the scaphoid and in the tubercle can be set in a thumb spica cast leaving the elbow free.
- Surgical stabilization is considered if there are no signs of healing in 6–8 weeks. Surgery avoids further complications due to prolonged immobilization. A protective splint should be worn during training for 6 months to protect during direct contact and avoid the risk of a second fracture. Since fractures of the proximal third or quarter of the scaphoid require 4–5 months of immobilization, surgery is suggested.

Compound fractures require surgery with a fixation screw [87] and splint protection for 4–6 weeks. Early mobilization can begin from week 2 according to the Indiana protocol [88].

16.9.4 Fractures of the Lunate

Noncompound fractures of this type are immobilized with the MCP joints flexed to reduce compressive forces. Compound fractures are treated surgically, and return to activity must be accompanied by a protective splint during training. All lunate fractures must be monitored to exclude onset of Keinböck syndrome. Pain must be kept under control.

16.9.5 Fractures of the Triquetrum

They account for 3–4% of all carpal fractures but are second in incidence among carpal fractures in sport. They are generally caused by falling on a dorsally flexed wrist with ulnar deviation, typical of skating. The dynamic can be impingement of the ulnar styloid or hamate that impacts on the margin of the triquetrum or avulsion of the dorsal, radiotriquetral, or scaphotriquetral ligaments with the wrist under palmar flexion. The wrist is immobilized for 4–6 weeks in a splint in the case of athletes who practice contact sports. Fractures of the body of the triquetrum are less frequent and caused by severe wrist trauma; they involve major injury to the ligaments and are treated with surgery.

16.9.6 Fractures of the Trapezium

They occur during falls with the thumb abducted. Compound fractures of the body of the trapezium are treated surgically. Fractures of the volar crest are difficult to recognize. They are identified clinically because the patient complains of pain at the base of the thumb and on flexing the wrist. Immobilization in a splint is similar to that for scaphoid fractures. If fracture of the crest also involves avulsion of the tip, it is advisable to maintain the thumb abducted.

16.9.7 Fractures of the Trapezoid

They are often accompanied by subluxation of the second metacarpal. They are treated surgically using screws and K-wires to correct the luxation for 6 weeks. The athlete can resume activity wearing a sporting splint.

16.9.8 Fractures of the Capitate

They often occur with the wrist hyperextended during radial deviation. They often suffer from malunion, risk of necrosis, or incomplete healing and should therefore be monitored carefully after removal of the cast. Noncompound fractures must be immobilized for 6–8 weeks. The athlete resumes activity only when diastasis is 1 mm or less; otherwise, there is instability. If the fracture is compound, surgery is recommended, and a sporting splint should be worn on resumption of activity. A bone graft may be necessary to avoid collapse of the carpal bone [85].

16.9.9 Fractures of the Hamate

They should be immobilized, although certain studies have observed that this may increase the risk of flexor digitorum profundus (FDP) [89]. Biomechanical studies suggest that excision of the hook may lead to reduced flexing force and recommend reduction with internal fixation [90]. Excision of the hook is in any case the elective surgical treatment and allows the athlete to resume activity after 6 weeks [91].

16.9.10 Fractures of the Pisiform

They occur as a result of direct trauma or falls with the hand outstretched. Noncompound fractures are immobilized for 3–6 weeks. Compound fractures that involve variation in the relation between the pisiform and pyramidal bones can cause persistent pain during gripping and radioulnar movements. A padded glove is recommended on resumption of activity.

16.9.11 Wrist Ligament Injuries and Instability

The distal row of carpal bones is more mobile and anatomically more unstable than the proximal row. The stability of the proximal row is ensured by the wrist ligaments. By instability we mean dyskinetic imbalance of load transmission and dyskinematic transmission of movement in the wrist caused by injury [92]. Larsen et al. [93] classified carpal instability on the basis of six characteristics: chronicity, severity, etiology, site, direction, and models. For rehabilitation, chronicity (acute/subacute or chronic injury) is an essential parameter to know for designing conservative treatment or surgery. The healing potential of acute lesions is likely to be optimal. In the case of subacute injury, the ligaments may not heal as well in the first 6 weeks as a consequence of retraction and necrosis of their remnants. In the case of chronic injury, primary ligament healing after 6 weeks is possible but very unlikely [94, 95]. In carpal dynamics, we observe that rotator mechanisms of the distal row have a significant effect on carpal stability/instability after injury of the scapholunate and lunotriquetral ligaments. Under normal conditions, the scaphoid and pyramidal bones rotate under flexion. Injury of the wrist ligaments leads to instability, and carpal ligament instability evolves naturally toward osteoarthritis and scapholunate advanced collapse (SLAC) or scapho-nonunion advanced collapse (SNAC) [96] of the wrist.

16.9.12 Rehabilitation

- The physiotherapist should know what happens at biomechanical level and the surgical techniques that can be used to design a rehabilitation program and splint protection. The literature proposes splinting in the early phase of mobilization. It can be used to assist rehabilitation protocols aimed at limiting radiocarpal joint mobility and scapholunate ligament overload and at accelerating wrist functional recovery after ligament injuries around the proximal carpal row [97]. Considering the number of ligaments in the wrist, rehabilitation of carpal instability centers on proprioception [66] and strengthening tendons that stabilize the wrist. Hager [66] divides proprioceptive exercises according to tissue healing stages and conscious and unconscious stimulation (see specific section). Kabat [98] describes a scheme of four diagonal and spiral movements to perform during rehabilitation, inspired by the physiological movements of the wrist in sporting activity. These are part of a scheme for the upper limb that forms a synergic muscle chain.
- In the case of associated tendonitis or pain, it is advisable to wear a splint that maintains the wrist at 0° or slightly extended at night. To unload all wrist structures, we make a resting-position type splint with the MCP and PIP joints slightly flexed. The wrist should never be flexed as this could give rise to joint compression, reduction of vascularization, increased tension on healed structures, and risk of developing carpal tunnel syndrome (CTS) or CRPS.
- The site of healing should never be stressed before bone and tendon repair is complete.
- Restoration of extension must have priority over that of flexion of the wrist and fingers.
- Exercise against flexor resistance should never be elicited before cicatrization as it causes joint compression.
- Eccentric exercises with both limbs and median line crossover are useful for optimizing proprioceptive recovery (Fig. 16.20).

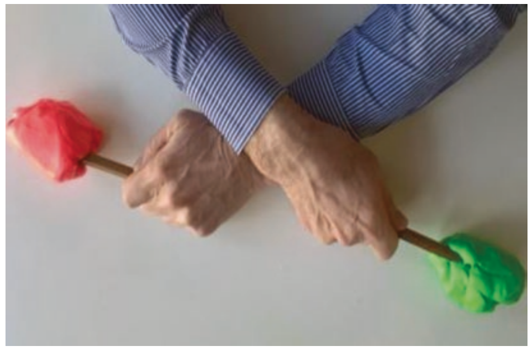

Fig. 16.20 Crossover proprioceptive exercises

16.9.13 Scapholunate (SL) Ligament Injury

This is the most frequent ligament injury. It occurs during forced palmar flexion of the wrist. It is treated conservatively in the absence of severe instability and provided there are no associated injuries to the accessory scaphotrapeziotrapezoid (STT), scaphocapitate (SC), or extrinsic ligaments. Biomechanically, when the SC ligament is injured, the scaphoid bone flexes in pronation, and the semilunar bone rotates in extension toward the palm, causing dorsal intercalated segmental instability (DISI) of the wrist.

Semilunar dissociation causes degeneration of adjacent cartilage and joint surfaces. Osteoarthritis develops gradually as so-called SLAC wrist, characterized by collapse of the anterior scapholunate ligament [99], which is not necessarily symptomatic [100].

Clinically we can define four types of instability: predynamic instability, dynamic instability, reducible static instability, and non-reducible static instability [101]. The first can be treated conservatively [99] by splinting the wrist, thumb included, for 6–8 weeks. This is followed by isometric muscle strengthening exercises involving the so-called "friends" of the scapholunate ligament that give the wrist stability:

- The *extensor carpi radialis* (ECR) muscle inserts into the second metacarpal bone, producing extension of the proximal row of carpal bones that move together with the metacarpals. Since it is located at the center of rotation of the wrist, the ECR is also a powerful supinator of the carpus and produces radial deviation.
- The *flexor carpi radialis* (FCR) muscle produces flexion and radial inclination of the carpus and pronates the pyramidal bone which in this position protects the scapholunate ligament. With the wrist in neutral or extended position, it causes compression of the trapezium on the scaphoid which flexes in supination.
- Contraction of the *abductor pollicis longus* (APL) flexes the scaphoid bone radially and the pyramidal bone toward the ulnar, closing the scapho-pyramidal space.

The "enemies" in the case of SL ligament injury are:

- The *extensor carpi ulnaris* (ECU) which when it contracts produces pronation of the capitate and scaphoid bones, increasing the distance between the scaphoid and the semilunar bones.
- The *flexor carpi ulnaris* (FCU) is the supinator of the distal row of carpal bones. Its contraction increases ulnar deviation of the scaphoid and causes radial deviation of the pyramidal bone, thus increasing radioulnar distance.

In conclusion, during rehabilitation of instability of the SL ligament, it is essential to strengthen the supinator muscles of the distal row of carpal bones (APL, ECR) and FCR and inhibit action of the ECU and FCU. Muscle strengthening should be accompanied by appropriate proprioceptive reeducation, paying attention to the fact that it can only be successful in the case of the FCR if the dorsal radioscaphoid capsule and dorsal SL ligament are intact [102].

16.9.14 Surgical Techniques

Various surgical techniques for carpal instability, which surgeons can apply according to the case and the patient's future needs, have been proposed in the literature. Rehabilitation depends on the surgical technique chosen as well as bone and tissue healing times. Here we describe the rehabilitation protocols for the most common surgical methods.

Direct repair of the dorsal part of the SL [99] ligament may be indicated in cases in which the tendons are vascularized and not retracted, in addition to anchorage of the SL joint with K-wires. If there is avulsion, the tendon should be anchored with a miniscrews or anchor. Direct repair of the SL ligament requires intact cartilage and intact scaphotrapeziotrapezoid (STT) and radioscaphocapitate (RSC) stabilizers. The rehabilitation protocol involves immobilization for 8–10 weeks until removal of the K-wires. Then a wrist splint is worn for 4 weeks. If the above requirements are not met, more radical intervention is necessary [94, 103]. In a study by A. Williams, 80% of athletes operated with the modified Brunelli technique [104] resumed sporting activity after 4 months [105].

16.9.14.1 Dorsal Radioscaphoid Capsulodesis

Described by Blatt [106, 107], this technique retensions the capsule dorsally and secures it with a K-wire. The wrist is then immobilized in a long-arm thumb spica splint for 2 weeks, after which the splint is replaced with a short-arm thumb spica cast leaving the IP free. This cast is changed periodically until 8 weeks. Rehabilitation begins at 8 weeks. The K-wire can remain in place until the third month, and in this case intercarpal movement is begun 3 months after the operation. In weeks 8–10, begin gentle AROM and PROM exercises of the wrist. In week 12, begin strengthening exercises and if full wrist flexion has not yet been achieved, the exercises can be more aggressive. Begin scar mobilization and PRN desensitization methods. Grip strengthening can begin 16 weeks after the operation. Continue wrist ROM exercises. Return to sport should be delayed for 6 months after surgery.

16.9.14.2 Four-Corner Arthrodesis (SLAC Procedure) [108]

The four-corner arthrodesis procedure removes the scaphoid to eliminate this focus of degeneration and fuses the lunate, capitate, hamate, and triquetrum to stabilize the wrist [108]. Since the most common complication after this procedure is dorsal radiocarpal impingement on wrist extension [109], certain authors propose fusion of the lunate in extended position [109]. The aim is to recover 50–60% of joint ROM and 80% of the force of the contralateral limb [110]. Various four-corner arthrodesis techniques have been described in the literature: they rely on K-wires, spider plates, staples, and screws [109–111]. The method of fixation chosen determines the postoperative course of therapy.

For rehabilitative purposes, Krakauer and colleagues [112] report that fixation with micro screws accelerates bone fusion, providing greater stability and allowing early mobilization. A long splint including the elbow is preferred; to avoid prono-supination, the thumb is also included, leaving the interphalangeal (IP) joint free. The elbow can be released from the splint after 4 weeks.

Rehabilitation protocol:

- *Weeks 4–6*: control of swelling and scar pain, tendon-gliding exercises.
- *Weeks 6–12*: if the bone has healed, isometric AROM exercises can begin. The wrist must not be loaded for 8–16 weeks [112].

16.9.14.3 Proximal Row Carpectomy (PRC)

This is a rescue technique consisting of removal of the scaphoid, lunate, and triquetrum. Various authors [109, 113, 114] have reported good short- and long-term results. Wrist flexion and extension may achieve a mean ROM of 70–80° with 8° radial and 19° ulnar deviation. It is possible to recover 71–79% of the force of the opposite wrist. Cohen and Kozin [109] sustain that there is no difference in the results obtained by PRC and SLAC.

Rehabilitation protocol:

- *Weeks 0–4*: wrist slightly extended (10°) [114, 115] in a splint with the fingers free to allow tendon gliding and isometric contraction of the extrinsic muscles of the wrist (flexors and extensors). Control of edema and pain. Mobilization of the elbow and shoulder
- *Weeks 4–6*: gentle AROM exercises of the wrist. Avoid combined flexion-extension of the wrist and fingers so as not to stretch the extrinsic muscles. Scar management, ultrasound treatment, and desensitization of the scar if necessary; light functional activity. Cautious wrist mobilization so as to avoid tendonitis

In this phase, the objective of rehabilitation resembles that of functional ROM exercises of the wrist. Certain authors have estimated a range of flexion-extension of 52–84% [116–118] with respect to the contralateral wrist. Radial deviation is more limited (9–10°) [113] while ulnar deviation remains practically unchanged (23–24°) [119]:

- *Weeks 6–8*: gradual weaning from the splint. AROM and isometric exercises; motor imagery exercises; starting at week 8, isotonic exercises and gradual recovery of strength by simulation of sporting movements. Certain authors [113, 120] sustain that after PRC, 50–83% of strength with respect to the contralateral limb can be restored within a year.
- *4–6 months*: plyometric exercises, gradual resumption of sport.

16.9.14.4 Total Wrist Arthrodesis

Rehabilitation protocol:

- *Weeks 4–6*: immobilization in plaster or splint until bone consolidation, usually for

6 weeks. A day splint with the fingers free may be alternated with a night resting position with the MCP joints included. Treatment of edema and scarring; gentle finger tendon gliding, preferring extension. Considering the long immobilization, mental training with the patient is useful.

– *After week 6*: weaning from the splint can begin subject to the surgeon's consent when bone repair is complete. Scar treatment continues also with silicone patches; pain control using TENS and draining any edema. Once the bone is stable, isometric exercises can begin with the surgeon's consent. Patients are given a 5-pound weight limit for the first 8 weeks [121]. Grip strength will not plateau until 1 year after surgery.

16.9.15 Lunotriquetral (LT) Ligament Injury

This injury is less frequent and has been the subject of less literature. It seems that falling on a hyperextended wrist with radial deviation and mediocarpal pronation can stretch the ulnocarpal ligaments enough to cause tearing of the LT [94, 122]. Under normal conditions, muscle load on the wrist causes supination of the scaphoid and flexion of the pyramidal bones. Instability of the LT ligament and tearing of the dorsal radiopyramidal ligament causes hyperflexion of the pyramidal bone, which when associated with supination of the scaphoid causes tearing of the LT ligament.

In cases of LT instability, the FCU, APL, and ECR tendons cause major flexion of the scaphoid that can degenerate into volar carpal collapse known as *volar* intercalated segmental instability (VISI).

The ECU protects the LT: it increases pronation of the scaphoid and triquetral and opposite rotation of the scaphoid and pyramidal bones.

In conclusion, in cases of LT injury, we should inhibit APL and ECR and increase the work of the ECU. Acute partial or postoperative damage to the LT ligament can be treated conservatively with a three-point orthotic that maintains the pisotriquetral block aligned with the rest of the proximal row [123]. Proprioceptive reeducation involves exercises to strengthen the hypothenar muscles on the ulnar column of the wrist and FCU muscles [94] (Figs. 16.21 and 16.22). Poor proprioception and inadequate neuromuscular control are what make most dynamic LT instabilities symptomatic. Many authors advise against conservative treatment on the basis of poor results [124–126].

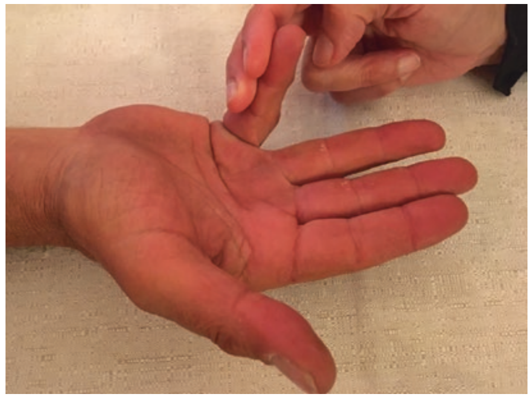

Fig. 16.21 Exercises to strengthen the hypothenar muscles on the ulnar column of the wrist

Fig. 16.22 Ulnar side extension of the wrist and abduction little finger resisted

16.9.16 Dorsal Impingement Syndrome

This syndrome is common in all sports involving repetitive wrist extension or axial loading. It is frequent in gymnasts (50% of cases) [127] and may be associated with stress fractures of the radius [128]. In the presence of a dorsal ganglion, the cause may be a torn scapholunate ligament followed by degeneration [129]. Treatments are splint, rest, and nonsteroid infiltrations. Surgery is recommended if symptoms do not resolve. In any case, return to sporting activity is postponed to after cessation of pain.

16.9.17 Ulnar Tendonopathies [130]

16.9.17.1 Extensor Carpi Ulnaris

Management of ECU tendinopathy is controversial but the treatment is typically non-surgical. Rehabilitation strategies are based on the severity of the injury [131]. Rest, activity modification, and immobilization will often resolve symptoms [132]. Some evidences recommend to wear for 4 months a long-arm cast with the forearm in pronation and the wrist in radial deviation and slight extension, thus the ECU tendon will relocate into the ulnar groove [133–135]. In the early reactive phase load management and isometric exercises until the pain settles are suggested. In chronic tendinopathy, without a sudden increase in pain, load management, eccentric work, isometrics, and strength exercises can help the recovery [135].

The same splint is suggested for ECU instability, but the immobilization period is 6–8 weeks [136]. Periodical stress tests are useful to verify the heal of the ECU sheath, in case of continued instability this condition may require prolonged immobilization or surgical management [137].

Post-operative management depends on the surgical procedure. In case of ECU sheath reconstruction, the immobilization in a long arm cast is still recommended until 4 months [134]. Return to sport or vigorous activity are forbidden for 2 months after immobilization is discontinued and therapy has begun [138, 139].

16.9.17.2 Ulnar Abutment

Conservative measures to reduce symptoms and avoid provoking movements allow the patient to continue sporting activity. Immobilization and infiltrations can reduce pain. In the case of chronic injury, cortisone infiltration is suggested [140]. If conservative treatment is unsuccessful, surgery is recommended to reduce rising of the ulna and to debride the TFCC.

16.9.18 Triangular Fibro Cartilage Complex [141, 142]

TFCC tears tend to occur in the dominant wrist. Many ruptures occur with radius fractures. Athletic activities that require upper extremity weight bearing, especially with the wrist in a hyperextended position, are more likely to cause TFCC disruption. After surgery, patients generally recover 80–85% of the strength of the contralateral limb.

Open or arthroscopic surgery of the TFCC should be followed by 4–8 weeks of immobilization in a splint that includes the wrist and elbow, edema and pain control, scar treatment, and AROM and PROM exercises of fingers and shoulder. In week 6, begin ADLs with less than 10 pounds. In week 8, begin slight pronosupination <45°, flexion 30°, and extension 30° of the wrist. After surgical repair of the TFCC, 3 months is usually necessary before the athlete can return to sport.

16.10 Hand Injuries

Sporting injuries to the hand are often caused by trauma such as falls, axial loading of digits, torsions, and grips. The athlete's main objective is to recover his/her previous level of competitiveness. Rehabilitation should observe the physiological foundations of healing of the tissues involved, educate the patient in compensatory strategies, and suggest the best methods of protection, defined by each specific sports league, until normal athletic movements can be resumed [143].

Resumption of sporting activity can first be accompanied by splints made of materials such as thermoplastic, silicon rubber, neoprene, and velcro strapping; these represent a compromise between freedom of movement of the athlete and the stability necessary for full functional recovery. It is the task of the physiotherapist to appropriately combine intervention with the patient's sporting technique.

16.10.1 Treatment of the Most Common Fractures in Combat Sports

How fractures are treated depends on their stability and degree. Fractures are defined as stable when they maintain reduction and when they do not displace spontaneously or with motion [144]. They are defined as nondisplaced when the bone profiles are not altered, as distinct from displaced fractures that require setting to prevent deformity.

- Fractures with internal stability (e.g., nondisplaced transverse fractures) can be treated conservatively with a splint, beginning controlled motion after 2–3 weeks.
- Potentially unstable fractures (e.g., oblique, avulsion, comminuted fractures) require protective splints that can be modified to allow incremental increase in ROM. In certain cases, they require coaptive hardware (e.g., K-wires), which however do not control rotation stress and therefore always have to be combined with a splint.
- Unstable fractures (e.g., long oblique, spiral, condylar, and irreducible fractures) with >30% joint involvement or with fragments separated by a distance of more than 2 mm can only be reduced surgically by means of fixation devices. Certain fixation devices enable immediate mobilization of the treated region, which however must be protected by means of a splint.

Depending on the type of conservative or surgical method used, immobilization time must be observed to allow complete healing of the fracture.

- *Close reduction*: involves immobilization of the region by splint for 4 weeks. PROM exercises begin from week 4–6, followed by AROM exercises until week 8, when progressive muscle reinforcement begins [145].
- *Internal fixation*: involves an early motion protocol that consists of mobilizing the surgical region beginning on day 7–10 [146]. In the case of multiple trauma involving tendon soft tissue, mobilization of repaired tendons can begin immediately together with early and continuous treatment of edema. To avoid adherences, the patient is taught tendon-gliding exercises (FDP, flexor digitorum superficialis (FDS), hook fist, intrinsic stretch, tenodesis) combined with ice (hot-cold gel pack or refrigerated lentils), compressive bandaging, and elevation. Muscle reinforcement can begin progressively starting at week 6.
- *External fixation/coapting implants*: involve immobilization by splint up to week 3–4 when the bone callus is "clinically stiff" [147] enough to allow controlled mobilization to begin [148]. Special attention must be paid to stabilization by K-wires. These are usually removed around week 4–6, but splint protection has to proceed for a further 2 weeks combined with hourly AROM exercises (without splint) to regain full mobility. Muscle strengthening exercises can begin around week 6–8.

Resumption of sporting activity is generally envisaged around week 10 for any type of fracture reduction [149].

16.10.1.1 Metacarpal Fractures

Fractures to the metacarpal bones may be caused by high energy trauma, especially in punching-type sports. About 35% of metacarpal fractures are treated conservatively [150] by splinting for a mean period of 4 weeks. The type of splint depends on the site and type of fracture.

- *Metacarpal base fracture:* the most frequent type involves the fifth metacarpal-hamate joint [151]. Both in the case of conservative treatment and after surgery, a splint including the wrist is used to prevent the tendon insertions from exercising force that could render the fracture unstable. The splint must be worn for 4–6 weeks.

- *Metacarpal shaft fracture:* these extra-articular fractures can be transverse, oblique, or spiral. The extrinsic flexor muscles of the fingers promote dorsalization, causing metacarpal shortening: every 2 mm of shortening causes an extensor lag of 7° [152]. Stable, nondisplaced and transverse fractures can be treated conservatively with hand-based splints that incorporate three pressure reduction points (1 dorsal and 2 volar) [153] allowing free active joint motion. For potentially unstable fractures, splints that include the wrist, MCP, and PIP joints are used. During healing the splint is shortened to enable controlled motion exercises. A similar splint is used for multiple fractures but also includes the fingers, while the MCP joints are held at 70° of flexion to reduce the effect of the intrinsic and extrinsic flexor muscles (Fig. 16.23) [154]. These fractures are usually subject to malrotation. To prevent this complication, the patient usually wears a buddy splint that binds the injured digit to an adjacent non-injured finger [155] (Fig. 16.24).
- *Metacarpal neck fracture:* this is the most frequent type of fracture in boxers. Direct trauma causes volar angulation of the metacarpal head. Such fractures must be promptly reduced to avoid intrinsic muscle deficit and proximal phalanx hyperextension. Then a splint is made with the wrist slightly extended and the MCP joints flexed at 70° to protect the collateral ligaments; a dorsal block component extending as far as the PIP joints, which are free to move, is also included [156]. Alternatively a hand-based splint with three pressure points over the palmar aspect of the metacarpal head can be built to apply a corrective dorsal force [157].

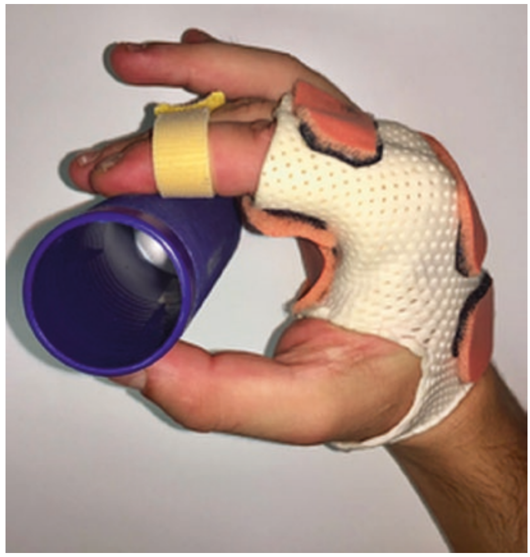

Fig. 16.23 Splint for metacarpal shaft fracture

Fig. 16.24 Buddy splint

- *Metacarpal head fracture:* these intra-articular fractures can involve the collateral ligaments, one or both condyles, and the joint surface. If the fracture is nondisplaced, a splint with the MCP joints flexed at 50–70° can be worn for 4–6 weeks [158]. For displaced fractures, internal fixation is necessary to allow protected motion [159]. Comminuted fractures causing substantial bone loss can be treated by external fixation [160] followed by immediate joint mobilization to stimulate healing of bone and cartilage [161].
- *Thumb metacarpal fracture:* transverse extra-articular fractures are the only ones that can benefit from conservative treatment

by means of splinting. Extra-articular oblique and intra-articular fractures must undergo surgery [153]. Bennett's fracture leaves a bone fragment on the volar-ulnar side of the base of the metacarpus. Rolando's fracture is a comminuted intra-articular fracture with fragments in "Y" or "T" configuration, leaving a volar-ulnar and a dorsal fragment. Surgery can employ K-wires, followed by a period of immobilization in a splint for 4 weeks or by micro screws that allow early but still protected mobilization.

16.10.1.2 Phalangeal Fractures

Phalangeal fractures are usually more unstable than metacarpal fractures since they are also the insertion site of the intrinsic muscles [162]. Because they respond poorly to immobilization, it is estimated that 84% of phalangeal fractures recover complete mobility [163], while the percentage drops to 66% when immobilization of the fracture lasts for more than 4 weeks [164]. In 19% of cases, the adjacent non-fractured finger loses motion [165].

Proximal Phalanx (P1)

- *Base fracture:* these are intra-articular fractures caused by an abduction force or by falling on an outstretched hand. After reduction of the fracture, a splint to hold the MCP joints in 70° flexion is made in order to balance the tension of the capsular structures and compress the fracture. A buddy splint with the adjacent finger enables early mobilization. The splint is worn for 2–3 [166] or 3–4 [167] weeks, and in the meantime the protected MCP joint is mobilized; internal fixation can be used to stimulate healing of joint cartilage [161].
- *Shaft fracture:* affecting digital flexor zone II, this fracture is termed "no man's land fracture" [168] and has a very poor prognosis [169]. About 90% of the bone surface is covered with gliding structures (central tendon, lateral bands, FDP tendon) that tend to form adhesions with bone callus if they are unable to glide, [170] limiting the motion of the PIP and MCP joints. The insertions of the interosseous muscles tend to volarize the fracture fragment while the extensors cause it to dorsalize [171]. Nondisplaced fractures are treated with a protective splint, and buddy strapping includes the neighboring non-injured digit in order to allow early active mobilization. The likely occurrence of extensor lag at the PIP joint can lead to fixed joint flexion contracture [172] and hyperextension of the MCP joint. To avoid pseudo-claw or pseudo-boutonniere deformity, it is suggested to make a dorsal splint that maintains the MCP joint flexed and the PIP joint extended. Tendon gliding is possible in this position, but complete flexion of the PIP joint is not allowed until the patient can maintain 0° extension [173].
- *Condylar fracture:* this type of fracture has been shown to respond better to conservative treatment than to reduction by internal fixation, probably because here the lateral bands and the central slip tend to readily form adhesions with the bone callus [150]. Immobilization of the PIP joint in completely extended position is advisable to avoid the development of flexed contractures; it is also suggested to perform short-arc AROM exercises every hour. In the case of internal fixation, continuous passive motion (CPM) allows regeneration of cartilage, reduction of edema and rigidity, and the prevention of adhesions [174]. Complete flexion of the PIP joint is not allowed until 3 weeks have elapsed.

Middle Phalanx (P2)

- *Base fracture*: the volar plate or the central slip is likely to be involved in this fracture. In the first case, when the fracture includes <20% of the joint surface, a buddy splint can be made and the immediate active motion protocol begun. If joint involvement is 20–40%, a dorsal digital splint is made with the PIP joint flexed at 40°; since it is free to flex, it transfers compressive force to the edge of the fracture. The splint must be worn for at least 6 weeks and the degree of extension gradually modified. If the damaged bone area is greater than 40%, internal fixation is advisable. In the second case, a splint to hold the joint in complete flexion is made and worn for 4–6 weeks; it should leave the DIP joint free in order to allow gliding of the lateral bands and oblique retinacular ligament. In the case of internal fixation with pins, a splint is made to hold the joint in complete extension for 2–3 weeks; the splint should only be removed for PROM exercises. With screw fixation, active mobilization is allowed immediately, and the extension splint is worn to prevent flexed posturing at the PIP joint. When the pilon is involved, for example, after severe compressive trauma, the intra-articular fracture is treated with dynamic traction orthoses to restore the length of soft joint tissue (ligamentotaxis) and to allow early passive mobilization [175]. The splint must be worn for 6–8 weeks and should only be removed when the patient is dressing/undressing [176].

- *Shaft fracture:* these fractures are quite rare but involve a risk of angulation and shortening of the shaft. This may be followed by imbalance of the extensor mechanism which in turn leads to loss of extension of the DIP joint and hyperextension of the PIP joint (swan neck). It is advisable to immobilize the joint for 3 weeks [177] in a splint with the MCP joint flexed and the PIP and DIP joints extended. If the fracture is reduced by internal fixation, active mobilization must begin in the first week, favoring gliding of the FDS at the PIP joint and of the extensor at the DIP joint.
- *Neck fracture:* this fracture is often displaced and unstable, thus requiring reduction with internal fixation [159]. Next the DIP joint must be protected against loss of active flexion and extensor lag by means of splinting in completely extended position; the splint should be removed frequently to allow gliding of the FDP.

Distal Phalanx (P3)

- *Base fracture:* these fractures often involve tendon avulsion. Treatment of tendon injuries is discussed in a separate section. Simple bone fractures can be treated conservatively with a splint that holds the DIP joint extended for 3–4 weeks while allowing movement of the PIP joint. If the fracture involves more than one third of the joint surface, surgery is necessary [178].
- *Shaft fracture:* these fractures must often be reduced by means of K-wires and splinted for 3 weeks, which allows immediate mobilization of the MCP and PIP joints. Mobilization of the DIP joint may begin from week 3. To improve the elasticity of the soft tissues, stretching exercises, paraffin baths, and FDP tendon gliding are recommended [26].
- *Tuft fracture:* compression is useful to protect and to reduce the pain and swelling of this painful fracture. A splint that holds the DIP joint in extended position while leaving the PIP joint free can also be used for comminuted fractures; the splint is worn for 2–3 weeks [179]. Active movement must be encouraged to gradually recover joint function. A return to normal use of the fingertip is helped by desensitization programs including vibration, putty press, and texture tolerance. In the case of a double bone fragment, the fracture can be reduced with K-wires followed by splinting with the DIP and PIP joints extended.

16.10.2 Treatment of the Most Common Ligament Injuries in Combat

Angular stress on the fingers can damage impair structures such as the collateral ligaments, which may even break when stressed in this way. Several studies indicate that during distortion, the collateral ligaments avulse proximally while the volar plate (VP) avulses distally [180, 181] and the radial collateral ligament (RCL) tends to be injured more than the ulnar collateral ligament (UCL) [182].

Ligaments are slow to heal because of their relatively poor vascularization [183]. This is why pain and swelling can persist for months, limiting movement.

The objective of the therapist is to prevent joint contractures and prescribe the right exercises for progressive recovery of ROM on the basis of lesion severity.

Ligament injury is classified in grades:

- Grade I: indicates a strained ligament; microfibrils tear but the ligament remains intact. Pain is elicited by palpation, and the angular stress test indicates passive instability of less than 20°. In any case, joint stability is ensured during AROM and PROM testing. The joint can be immobilized in physiological position for a week by means of splinting. Mobilization can then be undertaken with buddy splint protection.
- Grade II: indicates complete rupture or tear of the ligament without joint instability during AROM testing. This type of lesion can give rise to a small avulsion: the angular stress test shows instability >20°. The joint is splinted in physiological position for 2–4 weeks. Active joint mobility is only allowed with a buddy splint or with supervision of the therapist.
- Grade III: indicates a completely ruptured collateral ligament, associated with VP or dorsal capsule injury. Joint instability is absent during AROM, PROM, and the dorsal or volar stress test. The objective is to maintain concentric reduction during ROM testing. The splint must avoid dislocating positions; in more severe cases surgery is advisable.

16.10.2.1 Metacarpophalangeal Joints 2–5

The stability of these joints is imparted by the extensor mechanism of the sagittal bands, while palmar extrinsic stability is bestowed by the flexor tendon sheath with the A1 pulley attached to the VP [184]. The collateral ligaments ensure lateral stability of the MCP joint. Indeed, they are tensed during flexion, especially around 45°, and relaxed during extension.

- *Collateral ligament injuries:* these are not frequent and are often diagnosed late. Clinically, a passive deviation of >15° indicates a grade III lesion. Grade I and II injuries can be treated conservatively by immobilizing the joint under flexion in an intrinsic plus posture in such a way as to avoid the development of contractures during healing of the ligament. Grade III injuries can be treated with a buddy splint for 12 weeks (Fig. 16.25); if diagnosis is not delayed, surgical repair is advisable, especially in the case of professional athletes [185].
- *Dislocations:* these occur during falls on an outstretched hand with hyperextension of the MCP joints, and they often reduce spontaneously. Simpler volar or dorsal dislocations can be reduced manually under local anesthesia, after which the patient wears a dorsal blocking splint that holds the joints in physiological position and avoids their complete flexion. For open or irreducible dislocations, surgery is advisable followed by immediate mobilization with an exten-

Fig. 16.25 Buddy splint for injury of radial collateral ligament of the 5th MCP joint

sion block splint that keeps the MCP joint flexed at 30–50° to prevent instability.

16.10.2.2 Thumb Metacarpophalangeal Joint

The volar stability of the thumb joint is bestowed by the flexor pollicis brevis (FPB) and abductor pollicis brevis (APB) muscles. It is ensured by the collateral ligaments and the tendons of the extrinsic muscles.

- *Ulnar collateral ligament injuries (Stener's lesion)* [186]: injury to this ligament follows trauma to the thumb under radial deviation and hyperextension. Diagnosis is made by clinical examination [187]. Injury to the ligament is indicated by laxity exceeding 30° in the stress test or at least 15° more than contralaterally [188]. Grade I and II injuries can be treated by a hand-based thumb spica splint (Fig. 16.26) that leaves the IP joint free, worn for 2–4 weeks. After the period of immobilization, exercises to restore ROM and force can begin and should be incremented for 3–4 weeks. Active tip pinch or grasping are not allowed until week 8. In the case of avulsion or damage to more than 30% of the joint surface, surgery is indicated and splinting for 4 weeks. Between weeks 4 and 6, work should begin on recovering ROM with protection. The athlete can return to sporting activity after 3 months.
- *Radial collateral ligament injuries:* forced adduction combined with rotational stress can damage this ligament, causing ulnar and volar subluxation of the proximal phalanx. Diagnosis is by clinical examination, as for injuries to the UCL. Small avulsions can be immobilized with a hand-based thumb spica splint leaving the IP joint free; more severe cases (volar subluxation >3 mm and laxity >30°) require surgery. The rehabilitation protocol is similar to that for UCL injury, except that the thumb must be protected from any varus stress for 8 weeks.
- *Dislocations:* in the case of hyperextensive dislocation, proximal avulsion of the VP may occur, while hyperflexion may tear the dorsal capsule or the extensor pollicis brevis (EPB) tendon. After stable reduction, the joint must be immobilized in a splint that holds the thumb in opposition and slight flexion for 3 weeks. Recovery of ROM has to occur progressively.

Fig. 16.26 Hand-based thumb spica splint

16.10.2.3 Proximal Interphalangeal Joint

The stability of the proximal interphalangeal joints is ensured by their bicondylar nature, which together with the ulnar and radial collateral ligaments protect these joints from lateral translation. Their proper and accessory collateral ligaments provide further stability, the former being tensed during flexion and the latter during extension [189]. The VP forms the base of the PIP joint and prevents hyperextension. Dynamic stability is ensured by the tendons of the flexor and extensor muscles.

- *Dislocations:* dorsal dislocation is the most frequent [190]. Most cases can be treated conservatively with a digital block splint. To limit extension a figure-of-8 orthotic is made that allows active flexion of the PIP joint and avoids subluxation [191]. In cases of avulsion of the base of the middle phalanx, a finger splint is worn for 3 weeks followed by mobilization exercises. It is always a good idea to protect the central slip to avoid pseudo-boutonnière deformity, which is the most frequent complication after this type of injury [192].

- Volar dislocations are less frequent but more problematic because they can cause avulsion of the dorsal insertion of the central slip [193]. Reduction may be conservative with a splint that keeps the pulse slightly extended and the MCP joint physiologically flexed in order to loosen tension in the intrinsic and extrinsic extensor muscles. If this does not work, surgery is recommended [194].
- *Collateral ligament injuries:* are very frequent, especially among athletes. Injuries that cause slight instability are treated conservatively with a buddy splint and early ROM exercises. Return to sporting activity is only immediate if the splint can be worn during activity; otherwise, it can begin after 3 weeks. However, if moderate laxity is present after the trauma, it is necessary to make a splint and wear it for 2–3 weeks. Patients must be instructed in the correct exercises to restore ROM and can resume sporting activity after 4–6 weeks.
- *Volar plate injuries:* may be isolated or associated with injured ligaments. The suggested protocol in the acute phase and for slight injury [195] involves wearing a serial pro-extension splint which is modified over 4 weeks, starting from about 40° flexion of the PIP joint (Fig. 16.27). To avoid the development of contractures, it is suggested to begin protected mobilization at week 3.

16.10.3 Treatment of the Most Common Tendon Injury in Combat Sports

Tendon injuries considerably affect hand function and are arduous to treat because they require in-depth knowledge of anatomy, the stages of tissue healing, and the latest and most valid rehabilitation protocols. After surgical repair, tendons used to be immobilized in casts because suturing failed. This led to the formation of adhesions, stiff fingers, and loss of motion. Since the 1960s, the practice of early mobilization after tendon repair, combined with advances in surgery, has brought improved outcomes [196–198]. The new protocols involve the use of postoperative orthotics made of various materials (thermoplastics, rubber bands, neoprene, leather), which accelerate and simplify the management and rehabilitation process.

In this section, we deal with the most common tendon injuries in combat sports. For the postoperative treatment of injuries of the flexor and extensor tendons, see the latest protocols in the literature [199, 200].

16.10.3.1 Sagittal Band Injuries

The sagittal band is a recurring site of injury in boxers who may subject the area of the MCP joint to direct trauma [201], sustained forces [202], and sudden exertion [203]. Complete sagittal band rupture is what usually occurs [204],

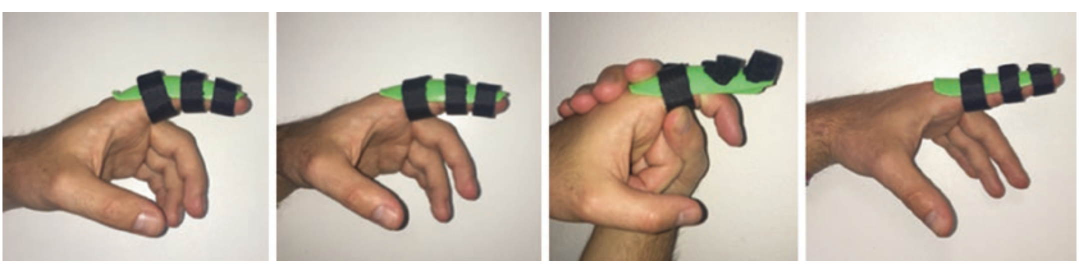

Fig. 16.27 Splint for VP injury

except in the long finger where the fibrous attachments of the extensor tendon are weaker than in the other fingers [205]. With involvement of the capsule or complete rupture of the radial sagittal band [206], surgery is generally required. For recent trauma, it is suggested to immobilize the MCP joint in neutral position for 4 weeks by means of a hand-based splint that allows movement of the IP joint [207]. Alternatively, it is possible to make a bridge orthotic that cradles the injured digit's MCP joint in 10–15° greater extension than the adjacent supporting fingers, for 8 weeks [207].

16.10.3.2 Mallet Finger

Disruption of the terminal portion of the extensor tendon at the distal phalanx may occur with or without avulsion. The clinical sign characterizing this type of injury is dropping of the DIP joint and inability to extend it. This may be accompanied by swelling and ecchymosis, but in many cases there is no pain [208].

Conservative treatment is the most appropriate, even in cases of bone involvement [209]. According to the best rehabilitative protocols [88, 210], also confirmed by our clinical experience, the DIP joint must be immobilized in a splint for 6 weeks in the case of recent injury and up to 8 weeks in chronic cases (≥22 days after injury) in order to obtain spontaneous repair of the tendon. It is important that the patient be examined weekly to test tendon status and to check for skin maceration. Indeed, patients who were not examined or who did not observe the times necessary for healing have shown poor outcomes [211]. Weaning from the splint can begin in moments of inactivity around weeks 8–10, but the splint must continue to be worn at night. Starting from weeks 10–12, it is only worn at night, and ROM exercises, if required, can begin at weeks 12–14. A recent study [212] showed that this was a valid protocol combined with cast immobilization (Fig. 16.28); it seemed to reduce DIP joint extensor lag by 50% with respect to treatment with a thermoplastic splint.

Fig. 16.28 Cast immobilization for mallet finger

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17 Neuromodulation for the Management of Peripheral Neuropathic Pain in Athletes Competing in Combat Sports

Regina Grippo-LeFauve

17.1 Neuromodulation and Peripheral Nerve Stimulation (PNS)

Peripheral nerve stimulation is emerging as a viable neuromodulatory therapy in the treatment for acute and chronic painful mononeuropathies. With the technological advances and customizable stimulation protocols, the utilization of PNS is now possible to assist in the management of acute and chronic pain syndromes in the extremities. With the recent advances and commercially available devices that are specifically designed to target the peripheral nervous system, healthcare professional can be more comprehensive in managing pain for athletes. Good patient selection and best practices will positively impact and promote the use of PNS in treatment of neuropathic and nociceptive pain.

One specialized area and population that could benefit from PNS are professional and amateur athletes competing in combat sports. Combat sports are defined as sports that entail physical competition between two athletes with a goal of physically dominating an opponent. The most common combat sports include wrestling, boxing, marital arts, and mixed martial arts. This is avunique group of injuries that occur during combat sports. Although there is no specific term for the diagnosis and management of these injuries as a group, the term "fight medicine" has been coined.

Because fighters are not always well informed and they do not always understand their injuries, they are vulnerable to home remedies and inept treatments and in some cases misguided by self-proclaimed experts. Understanding the mechanism of injury and appropriate treatment to manage pain should be the goal of the athlete and provider.

Knowledge of the complexity of pain as well as technological advances and proper training in administering evidence-based pain therapies is paramount in remediating and restoring function in these athletes.

17.2 Physiology of Nociceptive and Neuropathic Pain

Pain is a complex interaction of sensory, emotional, and behavioral factors. Awareness and a good understanding of how to treat the pain, its perception in the brain, and causalgia need to be well understood by the healthcare professional and the athlete involved in combat sports.

The International Association Society of Pain (IASP) defines pain as an "unpleasant sensory and emotional experience, associated with actual or potential tissue damage or described in terms of such damage".

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It is postulated that there are no pain pathways, only nociception pathways. Nociception is modulated at the level of the spinal cord and interpreted by the cortex, resulting in varying degrees of discomfort and pain. There are two main categories of nociceptors:

- Aδ fibers (10–20%) are thinly myelinated and transmit mechanothermal stimuli.
- C fibers (80–90%) are non-myelinated and are polymodal.

The Aδ and C fibers are high-threshold fibers. Inflammatory chemicals sensitize high thresholds. Silent nociceptors become active in the presence of inflammation and play part in peripheral sensitization.

Pain can be divided into physiological pain and pathophysiological, sometimes referred to as, clinical pain. Acute pain is defined as pain of short and limited duration. The pain is related to an identifiable cause (trauma, surgery, inflammation, etc.). Acute and chronic pain represents a continuum of a process where inflammatory neuropathic visceral and somatic pain plays a role. The CNS is not a hard-wired system; it allows for peripheral, central, intracellular, and synaptic modifications. Acute pain can result in long-term changes and a subsequently modified response to sensory input (neuroplasticity).

Physiological pain is the activation of nociceptors in response to a noxious stimulus, whereas neuropathic or clinical pain includes tissue and/or nerve injury and the inflammatory response. Physiological pain serves as a protective mechanism, is well localized, is transient, and is well differentiated from touch.

Understanding that nociceptive pathways are primary afferent fibers and the dorsal horn peripheral nociceptors are organs that respond to pressure, temperature, and chemical stimuli. The nociceptor cells are located in the dorsal root ganglia except for the fibers innervating the head and the oral cavity whose cell bodies are located at the trigeminal ganglion [1].

Neuropathic pain, by definition, is pain originating in the nervous system. There is no clear distinction between when neuropathic develops and nociceptive pain initiates this process, as they often coexist. Trauma and surgery cause nociceptive as well as neuropathic pain (cutting nerve endings), while pure nerve destruction sometimes results in an inflammatory process. Neuropathic pain can develop due to persistent pain over time and can change how the brain interprets the pain signal due to an amplification of signaling. The inflammatory process persists due to age related factors and lack of regenerative properties including diminished growth factors and proliferation.

Neuropathic chronic or clinical pain outlasts the stimulus and can spreads to non-damaged areas leading to primary hyperalgesia. Peripheral sensitization occurs as part of the inflammatory response. This can lead to the sensation of touch not being differentiated from pain (allodynia) or an increased response to a painful stimulus called (hyperalgesia). Antidromic sensory impulses result in the release of neurotransmitters from nerve endings of a primary afferent in response to noxious stimulation [2].

Competitive athletes are always looking for the most effective methods of modulating pain following injury. Unfortunately when the pain persists, a spiraling downward affect can occur quickly. Acute pain, or acute upon chronic conditions, often arises in athlete's due to old sport-related injuries that may not fully recover and over time result in neuropathic pain syndromes.

It is not uncommon that many athletes allow themselves to go down a destructive path in their need to get back to competition too quickly and without fully healing. Historically there has been a gap in treatment options when pain is refractory to medications until recently.

Peripheral nerve stimulation (PNS) was born out of a need to address very specific neuropathic pain complaints and furthers that possibility to treat acute and chronic nerve conditions. PNS is a patient-controlled anestietic, which decreases the perception of pain in the brain, without side effects, unlike pain medications that leave the patient feeling foggy, sedated, confused, or cognitively impaired.

Impairment and side effects of opiates should be considered carefully for athlete's partaking in combat sports that need to control their pain without it affecting their performance and cognition.

Peripheral nerve stimulation can be an excellent option for extremity pain in instances where conventional treatments, restoration/therapy decompression, and surgery methods have failed or surgical treatment is ruled inappropriate.

With the advent of novel technology and ultrasound guidance, PNS systems can be implanted effectively with 1) better precision and 2) a better safety profile and 3) are less invasive than other treatments that are traditionally used for peripheral nerve pain in the extremities.

17.3 Application for PNS and Neuropathic Pain

In the setting of combat sports, increased health risks related to prescription opioid are prevalent; thus, PNS is being examined to improve the acute pain experience that would be both beneficial and important in this population [3].

Pain management has ultimately been practiced using local anesthetics and medication as adjuvant treatment therapies for the past century [4]. The use of peripheral nerve stimulation (PNS) technology for acute pain is best described in the regional anesthesia and acute pain article by Ilfeld et al.

It is felt that with the advent of relatively recent developments in technology which now permits the easier application of PNS to treat acute pain as follows is due to: (1) the proliferation of accessible ultrasound machines, (2) the high prevalence of anesthesiologists with skills in ultrasound-guided regional anesthesia, (3) the development of a stimulator small enough to be easily implanted and to be adhered to the skin, and (4) the development of an insulated electrical lead specifically designed for percutaneous, extended use (up to 60 days) in the periphery.

17.4 PNS for Ulnar Nerve Pain

A common condition that can occur in boxing and other combat sports is ulnar nerve compression or impingement. This condition can occur in the elbow or wrist from blows to the inner elbow and secondary to the repetitive nature and impact of punching in boxing. The medial aspect or (inner elbow) during mixed martial arts or boxing can become inflamed, and fibrosis fibrotic in the area of the cubital tunnel (the groove between the medial epicondyle and olecranon of the ulnar grove) or on the ulnar side of the wrist known as Guyon's canal (a canal adjacent to the hook of the hamate) compresses the ulnar nerve causing ulnar tunnel syndrome.

Symptoms of ulnar nerve compression include sharp, shooting pain and paresthesias (tingling sensation) along the inner side of the elbow, wrist, and fingers. Symptoms can radiate up or down the arm. Physical examination is usually unrevealing except for reproduction of symptoms when the ulnar nerve is trapped (Tinel's sign). Radiographs are usually undiagnostic and electromyographic (EMG), or nerve conduction studies may be indicated for confirmation. The treatment depends on the location of impingement. In early phases, impingement included, EMG fails to confirm nerve damage.

Some fighters develop chronic debilitating persistent pain, and in some cases this may result in effecting or ending their careers permanently. Treating ongoing pain can be daunting. Clinicians unfamiliar with refractory nerve pain caused by combat sports may find it challenging to treat the origin of pain and pain symptoms as such. The medical providers including the ringside physician, occupational therapist, physiotherapist, fighters, trainers, and managers all need reliable information on combat sport injuries to ensue correct diagnose and course of treatment.

A comprehensive treatment plan begins with a multimodal approach to remediate pain and restore function in the extremity. In a multimodal approach to pain management, most physicians include first-line therapies such as rest, physical agent modalities, splinting, anti-inflammatory and compression aids for 4–6 weeks, and rehabilitation. Pain analog scales can be used to determine the effectiveness of treatment. Some cases may respond to anti-inflammatory agents and a series of corticosteroid injections. Injections may also aid in important diagnostic information as to which nerve bundle is generating the pain. If the patient is nonresponsive to pharmacological management and steroid injections and the pain persists over a 3-month period, other therapies may be considered.

Table 17.1 Levels of treatment interventions

Level 1
• Occupational/physical therapy, biofeedback
• OTC medications, NSAIDs, opiates
• Nerve decompression
Level 2
• Nerve blocks
• Peripheral nerve stimulation
Level 3
• Nerve ablation
• Spinal cord stimulators
• Implanted pumps

There are different levels of intervention which may be considered when first-line therapies do not work and pain persists. They are as follows: (1) decompression (release of pressure on a nerve trunk by surgical excision of constricting bands or widening of a bony canal) of the nerve, (2) nerve ablation (destruction of the nerve), or (3) ulnar nerve transposition (transferring of the nerve submuscularly out of the cubital grove). An algorithm of interventions that is often used in pain management consists of levels of intervention for management of shoulder pain in the post-stroke patients (Table 17.1).

Some patients or athletes may be nonresponsive to first-line treatments; thus, surgical intervention, such as decompression or ulnar nerve transposition, may be indicated. Following surgery of an ulnar nerve transposition, some patients may experience continued pain. This is sometimes referred to as a failed ulnar nerve transposition. For patients that continue to have ongoing pain, a PNS system could be considered as an interventional pain management option even prior to more permanent or irreversible interventions.

17.5 Review of the Literature

PNS has evolved over the past several decades and over 40 years ago. Wall and Sweet [5] inserted an electrode into the infraorbital foramen and found a decrease in neuropathic pain. They then successfully treated neuralgias using partially implanted percutaneous PNS [6–8]. Later, Sweet and Wepsic stimulated the median and ulnar nerves for the treatment of causalgia [9]. Variable success was reported in subsequent case series, 58% [10] and 52.6% for upper extremity pain relief and 31% relief for lower extremity pain [11, 12]. Difficulty with foreign body reaction related to the direct contact of the electrode on the exposed nerve limited the therapy until surgical technique utilizing fascial flap from nearby intermuscular septa was used to create a barrier between the nerve and the exposed electrode [13]. Stanton-Hicks suggested the following four criteria for patient selection: neuropathic pain in the nerve distribution, demonstration of pain relief by up to three targeted nerve blocks, exclusion of confounding psychosis, and positive response to transcutaneous electrical nerve stimulation (TENS) [14].

Over the next few decades of the 1970s, 1980s, and early 1990s, many small series were published utilizing a variety of electrodes and techniques for direct nerve stimulation or implantation in the vicinity of the peripheral nerve proximal to the region of pain to generate paresthesia distal to the implanted electrodes. Reports of long-term success were elusive, and results complicated by erosion, injury from the electrode insertion, and fibrosis in the peri-electrode area made the appeal of PNS largely wane in comparison to the success and ease of SCS dorsal column stimulation [15]. However, by the late 1990s with improving technique, Long [16] produced a meta-analysis showing positive effect in the reduction of pain in 82.5% of patients including sufferers of neuroma pain, painful diabetic neuropathy, and post-traumatic neuropathy [8, 17, 18]. Thereafter, Weiner, Reed, Slavin, and Burchiel were credited with renewing interest in PNS as they introduced percutaneous approaches to electrode implantation for remediation of greater occipital neuralgia and craniofacial pain syndromes [19–21]. Moreover, in the late 1990s, following Racz's publication refocusing PNS on CRPS [13], Hassenbusch et al. [22] published a prospective series of consecutive patients with chronic regional pain syndrome in the distribution of a single major peripheral nerve. He and his team implanted paddle electrodes on the affected nerves and tested them for 2–4 days.

The benchmark during the trail was at least a 50% pain reduction that was achieved by the generators output and ability to block the pain signal. Two thirds of the patients, followed for 2–4 years, reported good or fair relief, and pain was reduced from 8.3 to 3.5 on the numeric pain rating scale at follow-up.

Eisenberg et al. [23] published a large retrospective analysis looking at long term. Follow-up (3–16 years) of patients with PNS for nerve lesion reports "good" results in 78% of patients and an average drop in VAS from 6.9 preoperatively to 2.4 postoperatively. Mobbs et al. [24] retrospectively studied 45 patients with pain as a result of nerve trauma. At a mean follow-up of 31 months, the pain relief is judged as good (>50% improvement) by about 60% of patients and fair or poor in the remaining 40%. About half of patients reported increased activity levels. Long-term clinical outcomes of peripheral nerve stimulation for peripheral neuropathic pain were investigated by Van Calenbergh et al. [25] showing good clinical outcomes in five patients who underwent implantation of a circumferential electrode in the upper extremity.

Historically, most implanters have described dissection to a named nerve and direct application of either a ring or paddle lead in the vicinity of the nerve; this technique is technically demanding, has significant complication rate, and requires a considerable amount of operative time, and so recently interest in percutaneous trialing and permanent implantation has arisen. Speaking to that need, Monti [26] described percutaneous placement of electrodes for stimulation of the brachial plexus in the interscalene space.

The rise of ultrasound-guided injections and interventions has recently turned attention to the use of ultrasound to negate the need for direct dissection for peripheral nerve visualization as ultrasound can effectively characterize the peripheral nerve by density. Narouze et al. [27] have described ultrasound-guided placement of percutaneous electrodes next to the femoral nerve, and Huntoon et al. [28] in a series of papers have quite elegantly described a host of approaches for ultrasound-guided deployment of percutaneous PNS electrodes form neuropathic pain of the extremities [29–32]. While described by many authors, PNS for focal and radiating pain is toughly outlined by McRoberts [4] article that describes this in great depth.

The organization of the peripheral nervous system allows for direct named nerve stimulation for extremity pain. Stimulation of the peripheral nervous system for the treatment of pain has gained interest over the past several years as the modalities of delivery have become more robust and techniques have emerged that not only provide increased safety and ease of delivery but also improved success for the patient.

Recent outcomes have been demonstrated in the treatment of many painful conditions such as chronic regional pain syndrome; carpal, cubital tunnel syndrome; the painful postsurgical, traumatic, and entrapment injury; and focal pain of neuropathic and possibly nociceptive origins. PNS has been examined for postoperative pain because subsequently postoperative analgesia does not always outlast the pain resulting from nearly all surgical procedures. In addition, there are no risks of local anesthetic leakage or toxicity, allowing concurrent use of multiple leads. Also notable is that leads may be inserted with minimal concern of fascial planes between the uninsulated tip and target nerve because fascia impedes electrical current far less than local anesthetic.

The relatively early works of Weiner, Hassenbusch, and Stanton-Hicks [14] and others demonstrated that neuromodulation of the peripheral nerve resulted in paresthesia of the sensory distribution of the distal neural territory. However, placement required great technical skill in the dissection to the target and then in the placement of the neural electrodes in this manner. However, new developments in technology and single-lead insertions have made the procedure easier and less technical for the implanter to perform the procedure.

17.6 Mechanism of Peripheral Nerve Stimulation

Peripheral nerve stimulation (PNS) is a therapy that uses mild electrical pulses to stimulate the nerves of the peripheral nervous system.

The peripheral nerves make up a network of nerves outside of the central nervous system

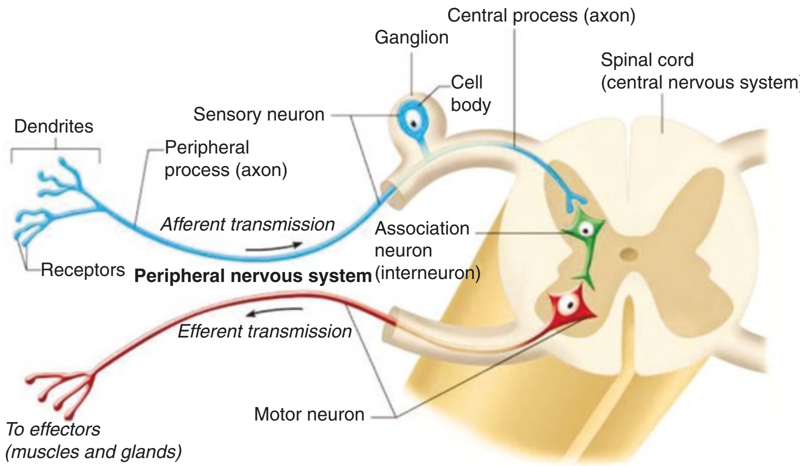

Fig. 17.1 Peripheral nervous system

(Fig. 17.1). For example, the ulnar nerve and median nerve in the arm are part of the peripheral nervous system.

While long observed that pain responded to touch, Melzack and Wall's 1965 introduction of the gate control theory of pain changed the paradigm of pain epistemology. The concept of early large fiber recruitment inhibiting small fiber conduction remains the basis of the theory of electrical stimulation and subsequent pain inhibition. Electrical stimulation of A-beta fiber afferents within peripheral nervous system is postulated to inhibit transmission of A-delta and C fibers. Stimulation of the peripheral nervous system opened the door for new ideas about the modulation of pain [6]. Their theory supported the concept of activation of A-beta fibers which conduct the innocuous stimuli of vibration and position and activate inhibitory interneurons within the substantia gelatinosa in the apex of the posterior horn and subsequently influence the wide dynamic range neuron onto which both the large and small pain fibers synapse. When this is activated, it is theorized; the gate closes and inhibits the cephalad conduction of pain.

There is some recent evidence that postulates interneuron inhibition, but applicability of this concept to stimulation remains somewhat controversial.

However, recently Ellrich and Lamp [33] showed the ability of PNS to suppress the somatosensory evoked potentials and subjective complaints of pain associated with noxious laser-induced nociception [34].

They additionally found and subsequently postulated that the much lower sensory threshold of A-beta fibers allows selective activation of those fibers in sensory nerves, while the exact mechanism of action is still unknown; the dense population of the subcutaneous layer with terminal A-beta fibers and similarity of this to direct peripheral nerve stimulation suggest that the presence of electrical field depolarizes those terminal sensory afferents without excitation of A-delta or C fibers. Their study of direct stimulation of the nerve in vivo demonstrated objective evidence of suppression of nociceptive propagation of the nerve signal to the central nervous system. This study provided objective and promising evidence for the antinociceptive effects of PNS and steered future studies regarding peripheral neuromodulation for pain and its implementation. Moreover, interest in new development of PNS systems and collaboration within the medical community have led to renewed innovation in this area.

17.7 Peripheral Nerve Stimulation of the Ulnar Nerve

Pathology of the ulnar nerve neuropathy can be due to trauma, compression, and/or entrapment to the nerve with pain within the ulnar distribution. The ulnar nerve is accessed superior to the medial epicondyle. One approach for positioning of lead is to have the patient supine with affected upper extremity in full shoulder flexion or prone with the upper extremity adducted and internally rotated for access. Placements deep to the nerve may be more stable over time [unpublished data]. The lead is placed with the remaining across the back of the arm along the triceps. Confirmation of the ulnar nerve is paresthesia to the ulnar distribution, lateral side of the forearm, fifth digit, and medial half of the fourth digit.

Patients who suffer from pain in an extremity within the distribution of a single or possibly two nerves may be good candidates for direct PNS. Percutaneously inserted leads providing analgesia can be placed near the targeted nerve 1–3 cm.

Other novel innovations used an implantable electrode placed around the peripheral nerve itself. While this has been reported as a challenging technique, there has been some success with this approach, it has been historically extremely invasive, requiring to necessitate direct peripheral nerve stimulation; the deployment of the lead is technically more demanding. Needle stimulators, ultrasound guidance, X-ray, or both may be used. Prior to consideration of trialing, the patient should undergo appropriate workup and screening. Huntoon et al. have spent considerable effort detailing several methods for trialing and implanting peripheral nerves with monographic guidance.

Each nerve has preferred loci for stimulation that diminish lead migration and movement. Some of the most common neural targets for intramuscular stimulation of the upper limb, trunk, and lower limb are shown in Fig. 17.2 which include (upper extremity) axillary nerve, suprascapular nerve, ulnar nerve, median nerve (trunk), superior cluneal nerve, intercostal nerve, ilioinguinal nerve, pudendal nerve (lower extremity), lateral femoral cutaneous nerve, tibial nerve, peroneal nerve, and saphenous nerve.

Patients initially undergo a trial blockade proximal to the pain with local anesthetic demonstrating at least 60–80% reliefs. If surgical intervention is indicated, referral to an orthopedic or neurologic surgeon with familiarity with peripheral nerve surgery must be considered. Physicians who are trained in the procedure can perform the implantation but may require additional training in ultrasound.

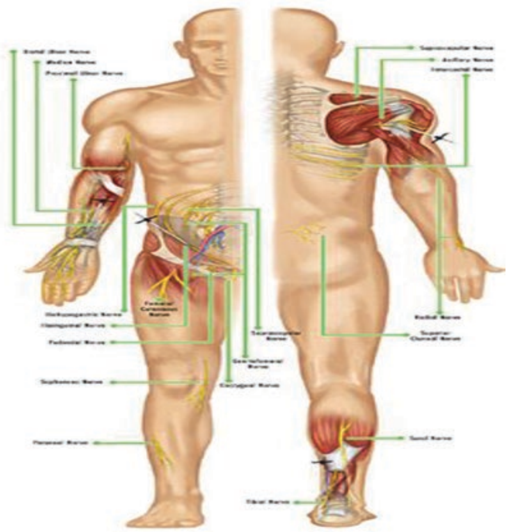

Fig. 17.2 Most common peripheral nerves stimulated. Upper extremity nerves: axillary nerve, suprascapular nerve, ulnar nerve, median nerve. Trunk nerves: superior cluneal nerve, intercostal nerve, ilioinguinal nerve, pudendal nerve. Lower extremity nerves: lateral femoral cutaneous nerve, tibial nerve, peroneal nerve, and saphenous nerve

Preoperative planning is essential as direct nerve stimulation is more complex. Mapping and familiarity of the neuroanatomy ensure proper placement of the lead. Placement is critical because PNS arrays (leads) are places traveling close to sensitive and often highly mobile structures including the nerves themselves. If possible, the patients should have leads placed while awake so that very careful needle advancement can be performed with strict attention to patients' reports of pain or paresthesia. However, the proxy of muscle contraction of the targeted nerve is confirmation of proper placement of the lead.

17.8 Types of Peripheral Nerve Stimulation Systems

There are currently three leading manufactures that provide physicians and clinicians commercially available implantable PNS systems. The option to place a temporary lead for 30–60 days or a permanent lead may depend on the chronicity of the etiology, patient selection, and familiarity with the device implant procedure.

Unlike spinal cord stimulator, a trial period may be optional with PNS but in the case of a permanent implant may make sense prior to fully implanting. However, controversy in this area exists among providers and manufacturers alike.

While all current devices are somewhat similar in ease of deployment and normally performed under local analgesic, each device has different unique features that can benefit the patient to mitigate pain and contribute to the overall ease of use.

The improved flexibility of available wire-thin arrays (leads) and external stimulators or generators allows the implanter great freedom in planning for stimulation implants, not only in terms of the variety of available neural targets and upstream from the pain but also the ability of the systems to provide customized programming and steering energy to various electrodes for neuromodulation of subelements of the patient's individual pain generators [2].

A unique system, SPR Therapeutics® (Cleveland, OH), received clearance from the US Food and Drug Administration to commercialize the SPRINT™ Peripheral Nerve Stimulation (PNS) System in July 2016. The SPRINT PNS System is the first and only completely reversible and minimally invasive peripheral nerve stimulation system cleared to provide relief of chronic and acute pain.

This system includes a threadlike lead and a wearable stimulator about the size of an Apple Watch® device. The lead is placed percutaneously, or through the skin, via a fine needle and connects externally to the wearable stimulator. The stimulator delivers electrical stimulation through the lead, which activates peripheral nerves to achieve pain relief (Fig. 17.3a).

SPRINT is unique in that it enables lead placement as far as 2 to 3 centimeters from the targeted nerve, allowing physicians to preferentially stimulate specific fibers of the nerve to maximize pain relief. This innovative approach to PNS does not require surgery or a permanent implant, meaning there is no tissue destruction as the system is designed to be withdrawn at the end of the treatment period.

SPRINT's percutaneous open-coil lead is placed using a 20-gauge introducer and is connected to an external stimulator. The intended treatment time is for 30–60 days and for 6 or more hours per day. Reports have demonstrated average pain relief of 59% and 82% in chronic pain conditions. PNS has also had promising results for acute pain.

Unlike conventional cylindrical leads/catheters, spacing between the open coils is designed

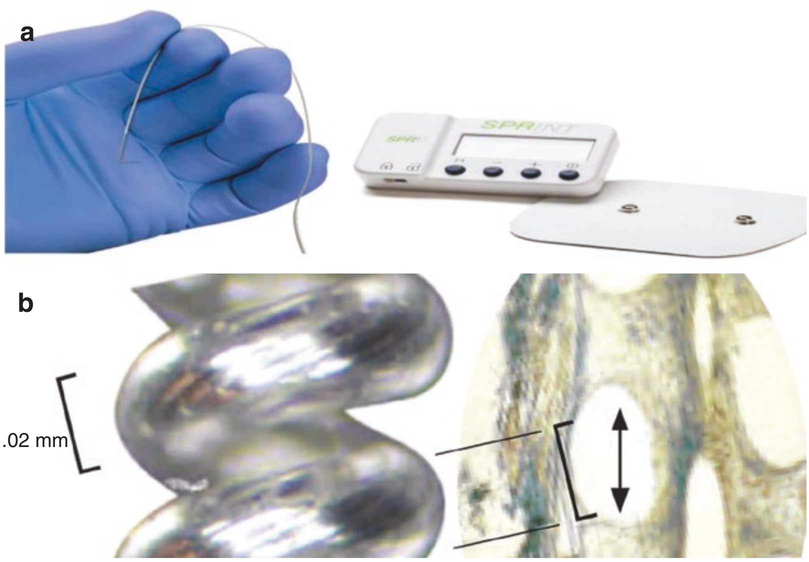

Fig. 17.3 (**a**) The three components of the SPRINT™ PNS system. Sprint patch, attachable PNS stimulator, and micro-lead. (**b**) The SPRINT PNS system open-coiled micro-lead. Designed for tissue in growth and encapsulation around the lead creating a barrier to pathogen ingress

to encourage in growth of fibrotic tissue (Fig. 17.3b). The tissue in growth and encapsulation around the lead can create a barrier to pathogen ingress. Combined with the small diameter of the lead, these factors can reduce the risk of infection.

StimWave (Fort Lauderdale, FL) received FDA clearance in May 2016 to market the StimQ. The StimQ PNS (peripheral nerve stimulator) (Fig. 17.4) systems treat chronic pain by targeting the peripheral nerve affiliated with chronic pain. The device is inserted through a needle and can be placed to stimulate any peripheral nerve below the head and outside of the spinal cord. The StimQ incorporates a trial period before planted permanently; there is a mandatory trial implant (3–7-day period) where you "test-drive" the stimulation to determine if it is effective for pain relief. After the trial device is removed and determined to help with pain relief, then the permanent implant is done.

If a temporary or short-term intervention does not remediate the pain, a permanent implant is available. One FDA-cleared device for debilitating chronic peripheral nerve pain is the StimRouter (Bioness, Valencia CA) that developed a small implantable lead powered by a wireless patch, (Fig. 17.5a) the external pulse transmitter (EPT), worn on the skin surface. StimRouter incorporates "electrical field induction" via a wearable technology that externally generates an electrical field that is captured by the receiver of the lead (Fig. 17.5b) just under the skin and transmits it to the electrodes at the lead tip millimeters away from the peripheral nerve.

A clinician can program the peripheral nerve stimulator (PNS), and the patient can control their customized programs and intensities through a wireless handheld remote. There are no implanted batteries to replace or recharge, and the small, 15 cm lead itself is implanted via an

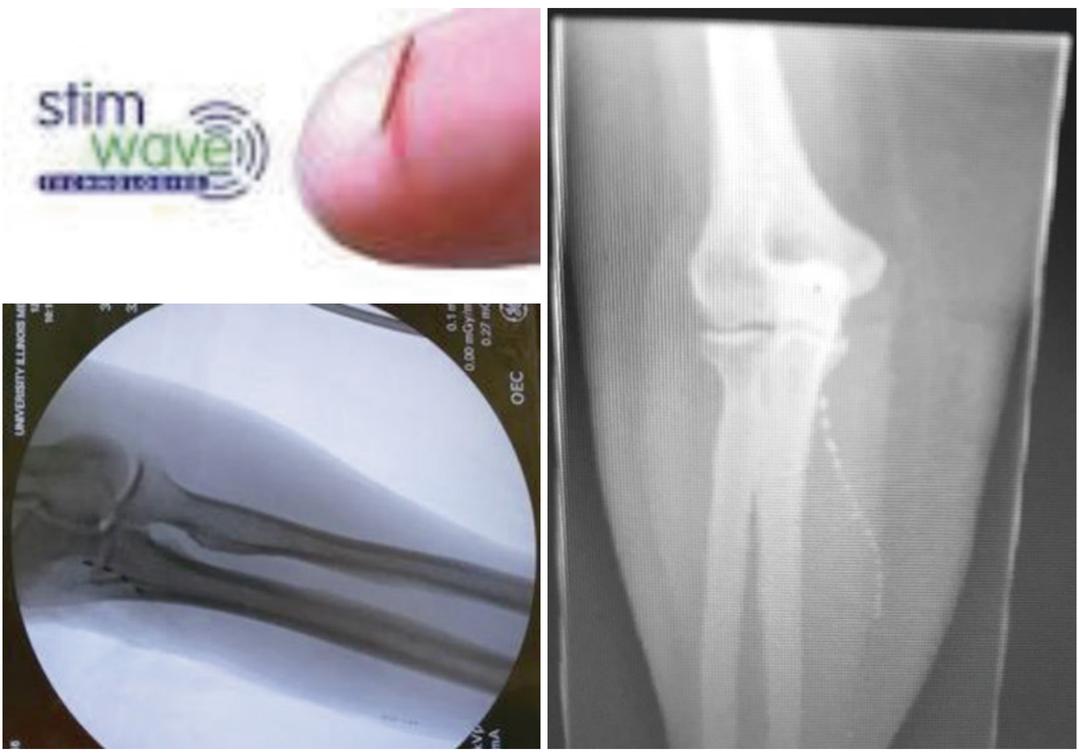

Fig. 17.4 The StimQ PNS (peripheral nerve stimulator) by StimWave

Fig. 17.5 (**a**) The StimRouter external pulse transmitter (EPT) by Bioness. (**b**) The StimRouter implantable 15 cm lead

injection-like approach with local anesthesia and a small incision. Daily management involves placing the wearable over the lead.

Pickup of the electrical impulse is achieved via an adhesive patch and activating the system with the wireless remote. Dosage levels and duration are stored in the EPT unit and can be accessed by the clinician during follow-up.

The StimRouter lead (Fig. 17.5b), with guidance by a stimulation probe with or without ultrasound or fluoroscopy, can be implanted via a direct approach in a 30-min procedure. Further research needs to explore lead location and long-term stability.

The nerve and the strength of the field generated by the EPT can be programmed and/or tuned to result in a desired pain relief level and any additional motor or sensory response, e.g., regimental patch under EPT from muscles or area near both electrical fields. The clinician can work with the patient to find the most appropriate stimulation program and stimulation intensity to achieve paresthesia. The patient ultimately controls intensity parameters.

Conclusion

This chapter focused on new trends in neuromodulation and future implications for interventional pain management in athletes competing in combat sports. Peripheral nerve stimulation has shown to be an increasingly viable option for many painful conditions including ulnar nerve pain with possibly nociceptive origins and neuropathic pain pathways. Procedural information on implantation of a PNS lead targeting the ulnar nerve distribution was provided. Technical aspects associated with implant and implied benefits for implanting externalized short-term and permanent devices were defined.

Neuromodulation for complexities of ulnar-sided pain in the peripheral nervous system, secondary to combat sports, may be a safe and effective alternative to manage acute and chronic neuropathic pain for athletes. More research and clinical data are needed to assess the reduction of pain that PNS can provide, the benefits over other treatment interventions [2], the long-term carry-over effects of short-term stimulation, and its impact on decreased pain and improved function in athletes competing in combat sports.

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Upper Limb Nerve Injuries in Sport

18

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Nerve injury in sports is not very frequent. According to the report of the Japanese Athletic Association in 1971, peripheral nerve injuries accounted for only 0.3% of sports injuries. Among all peripheral nerve injuries treated in their centre within 18 years, 5.7% were related to sports. The nerves most frequently involved were brachial plexus, radial nerve and ulnar, peroneal and axillary nerves in order of frequency [1]. The common mechanisms of injury were compression, traction, ischaemia and laceration [2].

A recent paper published in 2017 reported that sports-related nerve injuries accounted for around 0.5% of all traumatic peripheral nerve injuries [3]. Better understanding of sports biomechanics and preventive measures during sports could effectively reduce the number of injuries.

Nerve injury in sports could be classified into acute or chronic.

Acute injuries included:

- Blunt trauma
- Sharp injury
- Fracture ends laceration
- Acute traction

Chronic injuries were commonly caused by irritation or compression due to repetitive stress. For example:

- Muscle hypertrophy, fascial edge or increased compartment pressure causing compression
- Chronic inflammatory tissue causing compression
- Poor flexibility causing excessive traction at relative fixed point
- Subluxation with frictional injury

The underlying pathology of chronic nerve injury was usually due to ischaemia. When the critical threshold of 40–50 mmHg compression force was reached, inflammatory response and scar tissue formation would initiate. The sequel would be neurapraxia or axonotmesis types of nerve injury.

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18.1 A List of Common Sports-Related Nerve Injuries of Upper Limb

Nerves affected	Possible related sports
Brachial plexus	Rugby, football, wrestling
Spinal accessory nerve	Hockey
Suprascapular nerve	Weightlifting, volleyball, racquet sports
Long thoracic nerve	Ball games with overhead positioning of upper limb
Axillary nerve	Baseball
Musculocutaneous nerve	Body building, basketball
Ulnar nerve at elbow	Throwing sports, volleyball, weightlifting, racquet sports
Low ulnar nerve	Cycling, volleyball
Anterior interosseous nerve of median nerve	Long flexors hypertrophy
Low median nerve	Sports requires lots of wrist motion
Radial nerve at arm level	Direct contusion of humerus
Superficial sensory branch of radial nerve	Handcuff
Posterior interosseous nerve of radial nerve • Proximal at radial tunnel (radial tunnel syndrome) • Distal at forearm extensor compartment (PIN compression syndrome)	• Swimming, tennis, powerlifting (repeated forceful pronation and supination) • Windsurfing (prolonged repeated strong wrist dorsiflexion)
Digital nerve	Bowling

18.2 Brachial Plexus

Brachial plexus injury could occur in rugby, football or wrestler. In a study of Canadian football, brachial plexus injuries were reported to be 26% of players during the 2010 football season [4]. In an American football study, the lifetime rate of brachial plexus injuries was 50.3% [5].

The following three mechanisms were common to brachial plexus injury [6–11]:

(a) Traction caused by lateral flexion of the neck away from the involved side (similar to the mechanism in birth trauma)
(b) Direct impact to the Erb point causing compression to the brachial plexus (often associated with poor-fitting shoulder pads)
(c) Nerve compression caused by neck hyperextension and ipsilateral rotation (The neural foramen narrows in this mechanism.)

'Cervical nerve pinch syndrome', 'burner', 'stinger' or 'pinched nerve' were some popular terms to describe the injuries. Symptoms included burning or electric shock sensation over the arm. There might be arm numbness and weakness immediately following the injury.

Athletes were recommended to stop their sports activity until their symptoms were completely gone. This could avoid further injury. In case of recurrent symptoms, a special neck roll or elevated shoulder pads could be used during sports activities.

18.3 Spinal Accessory Nerve

Spinal accessory nerve was the eleventh cranial nerve. Common injury mechanism was blunt trauma or traction injury, such as lacrosse stick hitting across the posterior neck during hockey game, traction injury from a fall onto the shoulder.

Patient could experience shoulder pain, weakness in forward elevation and abduction of the shoulder. It might be associated with rotary winging of the scapula, in which drooping of the entire shoulder girdle with lateral displacement of the scapula could be seen.

18.4 Suprascapular Nerve

Sports requiring repeated shoulder abduction and external rotation could injure suprascapular nerve easily. Players in volleyball, weightlifting, racquet sports and basketball and free stroke swimmers were vulnerable. Mechanism was usually traction with excessive excursion.

Interestingly, studies reported that 10–30% of elite volleyball athletes had signs of suprascapular neuropathy. This observation lent credence to the term 'volleyball shoulder' [12, 13].

Traction injury and entrapment were common mode of injury. Limited excursion of the suprascapular nerve, less than 3 cm, was a risk factor for traction injury. Suprascapular nerve entered the infraspinatus fossa through the spinoglenoid notch, which was a potential compression site [14, 15]. Congenital narrow notch, a bifid transverse scapular ligament, calcified transverse ligament, and fractures predisposed to entrapment.

Patient with suprascapular nerve injury might complain of poorly localized pain at posterolateral portion of the shoulder. Atrophy of supraspinatus and infraspinatus can be seen. There may be insidious onset of shoulder weakness, especially abduction and external rotation. Injuries occurring at the spinoglenoid notch could result in isolated infraspinatus muscle atrophy and are pain-free. The condition could mimic rotator cuff tear.

Notch view x-ray, electromyogram (EMG) and magnetic resonance imaging (MRI) could be used as diagnostic tool. Imaging could also identify muscle atrophy and rule out other causes of external compression, e.g. ganglion.

Conservative treatment options included resting, activity modification, non-steroidal anti-inflammatory drugs (NSAIDs) and steroid injection. Rehabilitation exercise was also useful, e.g. rotator cuff strengthening, peri-scapular stretching and strengthening, scapular depression and retraction training. Surgical release of transverse scapular ligament was reserved when the above fails.

18.5 Long Thoracic Nerve

Typical injury mechanism of long thoracic nerve was stretching or traction upper limb in an overhead position, especially when the neck was turned to the contralateral side. Winging of scapula was the clinical sign.

Nonoperative management was the mainstay of treatment and included rest, symptomatic relief and therapy to maintain shoulder range of motion and strength and stability. The athlete should avoid heavy lifting or participating in activities that put the nerve at risk. Most cases subsided within 6–9 months, and almost all resolve satisfactorily within 12 months. Surgery was indicated only after 1–2 years of failed conservative management and no improvement in nerve function documented by electromyography (EMG) testing [16].

18.6 Axillary Nerve

Axillary nerve injury could occur in baseball pitcher. It was also called 'quadrilateral space syndrome'. The cause of axillary nerve irritation could be due to traction or osteophytes formation at posterior-inferior glenoid. Patient might present with vague posterior-superior shoulder pain. There might be deltoid weakness with extension lag sign. Electromyography (EMG) and magnetic resonance imaging (MRI) could help to make the diagnosis.

Patients should undergo an extensive rehabilitation training, involving scapular depression and retraction exercise to maintain normal scapulohumeral pattern. Shoulder joint contracture should be avoided at all costs as a loss of shoulder mobility might ultimately affect functional outcome despite a return of axillary nerve function. If no axillary nerve recovery was observed by 3–4 months following injury, surgical exploration was indicated [17].

18.7 Musculocutaneous Nerve

Isolated musculocutaneous neuropathy was rare. Patients with non-traumatic musculocutaneous neuropathies have been reported due to strenuous physical activity causing vigorous biceps hypertrophy, e.g. body builder, slam-dunker in basketball, athletes in weightlifting or rowing, throwers, etc. [18]. Sensory branch of musculocutaneous nerve was compressed during elbow extension and forearm pronation, as the lateral edge of the biceps aponeurosis impinged on it.

Patient might complain of burning or dysaesthetic pain in the forearm. There might be lateral bicep tenderness. Nerve conduction studies could find absent antebrachial cutaneous response.

Local lignocaine and steroid injection test could be both diagnostic and therapeutic.

Operation might be needed for removal of a wedge of biceps aponeurosis at the nerve compression site.

18.8 Ulnar Nerve at Elbow

Ulnar nerve neuropathy was the most commonly injured nerve in sports. It was highly susceptible to injury during overhead athletic activity and particularly vulnerable in throwing athletes. The combination of valgus forces and rapid extension resulted in tensile forces along the medial side and compression on the lateral portion of the elbow as well as shear forces in the posterior compartment. This combination was referred to as valgus extension overload syndrome and was the basic pathological model for most sports-related elbow injuries [19].

The ulnar nerve could be injured acutely via a direct blow to the back of the elbow during contact sports. Nevertheless, ulnar nerve injury more commonly results from traction or compressive forces at the elbow due to repetitive overuse during overhead athletic activity. Ulnar nerve dysfunction could be caused by excessive elbow valgus forces, especially in baseball pitchers, compression at the cubital tunnel associated with repetitive stress or spur formation in the ulnar groove with subsequent nerve compression [20, 21]. Patients with subluxation of ulnar nerve were prone to injury by friction.

Ulnar nerve passed through arcade of Struthers. It then travelled posterior to medial epicondyle through cubital tunnel underneath the ligament of Osborne. After it exited the tunnel, it passed between two heads of flexor carpi ulnaris. Free gliding of ulnar nerve in cubital tunnel was crucial during elbow flexion and extension. Ulnar nerve elongated an average of 4.7 mm from elbow extension to full flexion [22].

Traction injuries to ulnar nerve could be due to sustained repeated valgus stress at the elbow, together with tension overload during late cocking and acceleration phase of throwing. Pressure in cubital tunnel increased threefold during elbow flexion and wrist extension and up to sixfold during the late cocking phase. Similar biomechanics occurred in volleyball spiking. Ligament of Osborne, the roof of cubital tunnel, stretched 5 mm for every 45′ elbow flexion. Medial head of triceps translated 7 mm medially during elbow flexion; therefore, hypertrophy of the muscle could cause compression to ulnar nerve [23]. Similarly, hypertrophy of flexor carpi ulnaris could be another reason of nerve compression. Space-occupying lesions like scar adhesions, calcium deposits and osteophytes could also lead to nerve compression.

The clinical presentation was similar to cubital tunnel syndrome. Symptoms could be exacerbated by overhead activities or extreme elbow flexion. Diagnosis was confirmed with nerve conduction studies.

Nonoperative treatment aimed at optimization of throwing biomechanics and correction of movement pattern. Options of surgery included open or endoscopic cubital tunnel release, anterior transposition of ulnar nerve and medial epicondylectomy. All options yielded comparable results [24, 25]. Endoscopic cubital tunnel release could hasten rehabilitation time. Anterior transposition of ulnar nerve could effectively deal with traction and subluxation problem of ulnar nerve. In case of medial epicondylectomy, maximally 20% of medial epicondyle could safely be removed without detachment of medial collateral ligament [26]. Otherwise, there might be complication of elbow instability.

18.9 Low Ulnar Nerve

Low ulnar nerve injury was associated with cycling or mountain biking. Chronic external compression over ulnar palm with the wrist in dorsiflexion caused compression at deep terminal branch of ulnar nerve. There was high load over the nerve especially going downhill, while the body weight of athletes was supported by the base of the palm.

Clinical presentation depended on the exact compression site within Guyon's canal. There might be intrinsic hand muscle wasting. Patient might have motor or sensory deficit or both.

Other possible differential diagnoses included:

1. Ulnar hammer syndrome in judo or karate player (post-traumatic digital ischaemia from thrombosis of ulnar artery at Guyon's canal)
2. Ulnar nerve compressed by ulnar artery aneurysm (presented with cold intolerance and ulnar finger numbness)
3. Fracture hook of hamate
4. Ganglion cyst in Guyon's canal
5. Ulnar carpal instability
6. C8, T1 radiculopathy
7. Motor neuron disease

Treatment was usually conservative, which included adaptation and accommodation of sitting position of bikers, proper use of padding and gloves, adjustment of bike handle bar design, etc.

18.10 Anterior Interosseous Nerve of Median Nerve

Anterior interosseous nerve of median nerve palsy was a rare condition. Marked forearm muscle hypertrophy caused effort compression to the nerve. If conservative treatment failed, operation for release of all related fascial bands (flexor digitorum superficialis, pronator teres, accessory bicipital aponeurosis) was indicated.

18.11 Low Median Nerve

Median nerve at carpal tunnel could be affected by sports requiring gripping or prolonged repetitive flexion and extension of the wrist. Clinical presentation was basically the same as carpal tunnel syndrome. Patient might present with exertional paraesthesia in the hand, wrist and forearm. There might be sensory deficit at radial 3.5 digits and thenar muscle weakness. Tinel's sign and Phalen's sign could be positive. Nerve conduction studies could be used to confirm diagnosis.

Conservative treatment worked in majority of cases. It included nocturnal splint to keep the wrist in neutral or dorsiflexed position and modification of sports movement. Surgical treatment was indicated if there was no improvement after conservative management. Operation for carpal tunnel release could be done by open or endoscopic method. However, there might be postoperative weakness of forearm flexors due to loss of flexor retinaculum as a pulley [27]. It could be an important concern for athletes.

18.12 Radial Nerve at Arm Level

Injury to radial nerve could cause dropping of wrist and digits. It was associated with sensory deficit over anatomical snuff box. It could be caused by direct contusion of humerus. Majority of the radial nerve injuries in sports were neurapraxia. Anti-wrist drop splint could be used to wait for recovery.

18.13 Superficial Branch of Radial Nerve

Superficial branch of radial nerve at the wrist could be compressed by handcuff, wristbands or taping. The condition could worsen by repetitive ulnar deviation, pronation and supination of the wrist. Patient might complain of vague pain or paraesthesia over dorsoradial aspect of the wrist or thumb. Diagnosis could be confirmed by nerve conduction studies. Treatment included resting splint with the wrist in supination. Surgical release was rarely needed.

18.14 Posterior Interosseous Nerve of Radial Nerve

18.14.1 Radial Tunnel Syndrome

Radial tunnel started from the level of the radiocapitellar joint, extending distally past the proximal edge of the supinator boundaries. It was about 5 cm in length. Sports requiring repeated forceful pronation and supination of the forearm, e.g. swimming, tennis and powerlifting, could lead to radial tunnel syndrome. Patient might complain of pain over lateral elbow distal to lateral epicondyle. It could mimic tennis elbow.

Physical examination showed increased pain with resisted middle finger extension with the forearm in pronation and elbow in extension. Conservative treatment was usually effective.

18.14.2 PIN Compression Syndrome

Windsurfing always required prolonged repeated strong wrist dorsiflexion. This could lead to exertional compartment syndrome of the posterior muscle compartment of the forearm. Patient could present with progressive weakness of finger extensors during training. Conservative treatment options included resting, non-steroidal anti-inflammatory drugs (NSAID) and muscle stretching programme. Sometimes, patient might require prophylactic fasciotomy to release the posterior interosseous nerve of radial nerve.

18.15 Digital Nerve Compression

A common example was repeated trauma to ulnar digital nerve of the thumb in bowling players. Compression was caused by scar tissue formed around the nerve. It could be prevented by use of protective padding during the game. Temporary resting splints for the finger were a conservative treatment option. Surgery was rarely needed, e.g. decompression or nerve transfer.

Conclusion

Nerve injuries in sports were frequently caused by overuse. Clinical presentation could be vague at early stage, as symptoms usually occur after exertion. Protective measures (e.g. padding, splint, gear) could help to prevent injuries. Primary and secondary prevention by appropriate training programme and proper execution of movement pattern would always be essential.

For medical management in nerve injuries in sports, conservative treatment frequently worked. Sometimes, surgery like release operation or fasciotomy might be required.

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