Intraarticular Fractures

Minimally Invasive Surgery, Arthroscopy

Mahmut Nedim Doral
Jón Karlsson
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“to my grandson OZAN”

Foreword

This is a book about *bones* and *joints.*

That is the same as *structure* and *function.*

Intra-articular fractures disrupt the structure and the function. The intact body is a marvelous machine. This book is about what happens when the machine breaks and what to do about it.

How many joints or articulations are in the human body? There are twice that many articular facets. Each facet is subject to intra-articular fracture. No one can master a system that complex. So this textbook is necessarily large; yet, it still addresses only the more common or more significant intra-articular fractures.

Dr. Doral has pooled the experts to create this masterpiece. Therefore, the book is essentially a brain trust—an organization of expertise on the innumerable ways to disrupt the marvelous human machine. What would—or what might—one do about these disrupting intra-articular fractures? Why would they choose which option? How do the options differ? How are they similar? How do we insert *judgment* into the choices?

In the simplest analogy, this textbook resembles the medical manual we all carried in the large side pockets of our lab coats as interns. We turned to that manual frequently and for summary information about unfamiliar patient issues. This is a similar "how-to" book. That is Dr. Doral's finesse—distilling various intra-articular fractures, their significance, and their treatment options into digestible bites for convenient reference or for succinct research, if needed.

Dr. Doral has engineered the textbook with organization, expanded it with point and counterpoint, and punctuated it with references. He assembled a team of critical editors who have disciplined the contributors for clarity and validation of their opinions. He insisted that the alternative treatment options be current and that they be justified.

The thankless and Herculean task of reviewing the chapter manuscripts of the numerous guest contributors fell to Dr. Jón Karlsson and Dr. John Nyland. Here, most editors would say that "reviewing" is such a small word. True, considering the efforts spent by Drs. Karlsson and Nyland. They dissected each chapter of the book into paragraphs and phrases, critiquing them in the detail necessary to ensure accuracy, grammar, expression, and readability. They researched every reference for correctness of volume and page number, a grueling chore for even the best of academicians. And they worked through every editorial revision with each of the authors, maintaining civil discourse with otherwise busy surgeons and physicians in the process. How admirable.

I have known Mahmut Nedim Doral since 1993. A mature and meticulous surgeon then, I have watched him mature even further and have seen him think more critically as his teaching experience and his international networking have both grown immeasurably. He gently coaxes the best from his contributing authors. He is the field marshal for orthopedic training. He knows what to teach, why to teach, and how to teach.

Working with him as a contributor has been at once an honor and also humbling. I am confident the readers and researchers of this comprehensive text will find rewards in the pages. And the rewards will increase with repeated reading, just like that intern's pocket medical manual. Those rewards must salute Dr. Doral and should reflect the finesse with which he has orchestrated such a thorough text on a complex orthopedic subject.

Framework and mobility. Bones and joints. Structure and function. Herein lies the essence of intra-articular fractures.

Richmond, VA, USA Terry L. Whipple

Preface

This book represents another novel product of sleepless nights, incorporating the valuable efforts of more than 100 clinician scientists from all around the world. Again, the journey of preparing this book with strong contributors has led to the creation of a work that incorporates comprehensive, higher-level science with direct clinical application. I have also tried to integrate Far Eastern science and sociocultural influences with Western perceptions. Science and reason are not restricted to any particular religion, language, race, color, or flag.

Intra-articular Fractures was created to address one of the leading causes of traumatic arthrosis and movement system dysfunction. The importance of using minimally invasive surgical treatments becomes more apparent each passing day, and greater use of arthroscopic surgical approaches must be encouraged. My attention was first drawn to this topic in 1992 when I listened to Terry Whipple during the International Arthroscopy Association Specialty Day at the American Association of Orthopaedic Surgery Meeting. Over the years, I have since been doing my best to disseminate the concepts that he presented to the world through International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine congresses and European Federation of National Associations of Orthopaedics and Traumatology symposiums.

This book represents a mission to obtain the knowledge, experience, and innovative expertise of authors from around the world regarding intra-articular fracture management. In so doing, we have assembled considerable information about minimally invasive surgeries, arthroscopic approaches, metaphyseal joint fracture management, enhanced adjacent soft tissue injury diagnosis, more anatomic repair, and earlier use of progressive joint range of motion and rehabilitation modalities. Innovative technologies such as virtual and augmented reality are also proposed to enhance surgeon training in these methods. In consolidating this information into one source, we hope to have created a practical guide for sports traumatologists, clinicians, and physiotherapists who work with patients who have sustained intra-articular fractures.

Many people invested long hours to create the book that you now hold in your hands. I am grateful and owe thanks to those who provided encouragement, friendship, wisdom, and patience. I would like to acknowledge special thanks to Dr. Jón Karlsson, Dr. John Nyland, and Dr. Terry Whipple for their great efforts in the preparation of this book. Over the last 3 years, their meticulous editing as well as their organization of the index have been invaluable contributions to bringing this project to fruition. I am also much obliged to Dr. Naila Babayeva and Dr. Gurhan Donmez for all their dutiful attention to detail and systematic work. Also, I would like to personally thank and recognize Ms. Aruna for her support as well as that of the entire Springer team.

Lastly, I would also like to express my sincere gratitude to Dr. Gazi Huri and Dr. Onur Bilge for their outstanding collaboration and thanks to Dr. Defne Kaya, Dr. Egemen Turhan, Dr. Ahmet Hakan Kara, Coşku Turhan, all chapter contributors, and friends.

More beautiful works...

With respect,

Ankara, Turkey Mahmut Nedim Doral

Preface

Over the last 20 years, orthopedic surgery has rapidly moved in the direction of being less invasive. One of the major reasons for this is to reduce surgical morbidity, with less joint scarring and stiffness compared to open procedures. This philosophical shift started when it became evident that the arthroscope was useful in performing a plethora of technically advanced procedures, e.g., inside the knee and shoulder joints. Nowadays, the arthroscope is used even in other joints with great success.

Minimally invasive fracture surgery has evolved over recent years, and today, it provides a good alternative to wide-open surgery, where fractures are exposed through a large incision or an arthrotomy. In many cases, fractures are being operated on using minimally invasive techniques in combination with fixation plates and screws. Intra-articular fractures often lead to joint impairment and degeneration if reduction is not accurate. Adequate fracture site visualization is often difficult, even under fluoroscopy guidance, and this may lead to less than accurate reduction. It is in such circumstances that arthroscope use may strongly enhance surgical effectiveness. In addition to washing out the joint, arthroscope use can assist with achieving precise articular surface fracture reduction, even when small fragments exist.

This book is about minimally invasive and arthroscopic-assisted surgical techniques that often are very helpful in surgically managing intra-articular fractures. Many different techniques are shown, and the book is enriched by clinical photographs, radiographs, and arthroscopic images.

We are convinced that arthroscopic techniques will continue to evolve with even more innovative minimally invasive and arthroscopic-assisted surgical techniques being developed in the near future.

Finally, I would like to express my sincere gratitude to my co-authors and friends, Professor Mahmut Nedim Doral and Professor John Nyland, for their collaboration with this work. Also to all contributors, who with great patience have written all chapters.

Mölndal, Sweden Jón Karlsson

Preface

Physiotherapists and athletic trainers often treat patients who have sustained intra-articular fractures. These interventions progress from immediate concerns about joint pain, effusion, and patient fears to strategies designed to improve range of motion, proprioception, muscle strength, neuromuscular control, endurance, power, and patient confidence or self-efficacy. Ultimately, patient care transitions to focus more on specific functions such as rising from a chair, stair climbing, running, jumping, throwing, reaching, and grasping within a context that simulates the activity, vocation, or sport that the individual desires and expects to return to. Although this care continuum represents a somewhat standard treatment progression, achieving specific goals can become moot if an intra-articular fracture is not effectively managed. Without the healthy "transmission" provided by natural joint movement, the powerful neuromuscular and cardiovascular and pulmonary system "engines" cannot function optimally.

Restoration of normal joint surface alignment, stability, and congruence increases the likelihood that chondrocytes will maintain articular cartilage health and function. Without this restoration, the joint will degenerate either through disuse or through continued use as both create abnormal joint forces. No matter what the patient's activity interests, joint health is essential. All too often, joint health is only given appropriate attention once an injury has occurred. Greater joint health consideration must occur during developmental childhood games and sports, adolescent competitions, club and college athletic sports, and adult recreational and vocational activities. Without joint health and the movements it enables, all body systems become impaired.

The thin articular cartilage layer does not merely represent the border between bone and synovial fluid. Rather, it represents the potential capacity for a patient to satisfactorily achieve pain-free movement goals and fulfill activity expectations. The surgical and rehabilitative principles mentioned in this book are largely grounded in preserving articular surface integrity and normalized joint movement, including subtle, but essential accessory "joint play" motions. With these essential factors restored, articular cartilage health is preserved, and degenerative joint changes are prevented or at least delayed.

I would like to thank my friends and colleagues, Dr. Mahmut Nedim Doral and Dr. Jón Karlsson, for the opportunity to assist with this fulfilling project. Also, thanks to all chapter contributors for their dedication to seeing this project through to completion.

Louisville, KY, USA John Nyland

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The editors would like to thank Gazi Huri, Naila Babayeva, Gürhan Donmez, Onur Bilge, Defne Kaya, Cosku Turhan, Terry Whipple, and the Springer-Verlag production team for the dedicated support that they provided over the development and creation of this book.

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Part I

General Knowledge

1 Natural History of Bone Bruise

S. Kemal Aktuğlu and Kemal Kayaokay

1.1 Introduction

Bone bruises cannot be easily identified through plain radiographic imaging. Since the late 1980s, magnetic resonance imaging (MRI) use has increased the diagnosis of these lesions (Berger et al. 1989; Mandalia et al. 2005; Vellet et al. 1991; Yao and Lee 1988). A bone bruise is defined as focal signal changes in subchondral bone marrow without any cortex fracture, microtrabecular fractures, hemorrhage, or edema (Rangger et al. 1998; Ryu et al. 2000). Bone bruises were primarily detected around the knee joint, especially after MRI to investigate anterior cruciate ligament (ACL) ruptures and other knee ligament injuries (Ege et al. 2001; Engebretsen et al. 1993; Graf et al. 1993; Vellet et al. 1991; Yao and Lee 1988). In contrast, hip, ankle, shoulder, wrist, and other small joint bone bruise injuries have been visualized less frequently than in relation to knee injuries. Bone marrow edema (BME) is frequently encountered on MRI examinations with the complaint of unexplained joint pain. BME is also seen in various joint diseases. There are ischemic, mechanical, and reactive conditions in the etiology of BME (Mink and Deutsch 1989). Microfractures, stress fractures, and bone bruises are seen in the mechanical etiologies of BME. BME without trauma has been described primarily at the hip joint. Unfortunately, there are few reports on the prognosis as well as short-term and long-term effects of these painful lesions. The resolution of bone bruises, effects on short-term recovery and function, long-term sequelae, and the clinical implications of these results are not yet well established. Bone bruises cannot be directly identified using standard radiographs. However, they can be detected on radiographs following the presence of accompanying avulsion fractures or fissures. Bone bruises are histopathologically based on edema and hemorrhage. Due to the fatty nature of the subcortical bone marrow, MRI of edema is mainly based on fat-suppressed sequences. While bone bruise appears in low signal intensity in T1 sequences, it is encountered in high signal intensity in T2-weighted sequences. In particular, it gives insight into the acuity of the T2 imaging lesion (Mandalia et al. 2005; Nakamae et al. 2006). More information can be obtained about the increased density of bone edema by the short tau inversion recovery (STIR) imaging in which the signal in the normal medullar is suppressed. Bone bruise and BME are often indistinguishable on MRI. The trauma history and clinical presentation of the patient must be taken into account to make a better distinction between the two (Figs. 1.1 and 1.2).

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Fig. 1.1 A 59-year-old male, ski injury. Medial knee pain. No visible lesion on X-ray

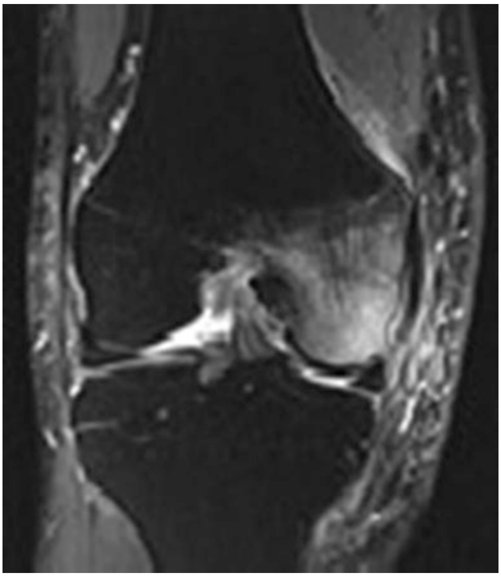

Fig. 1.2 The same patient. MRI view of osteochondral lesion, subchondral fissure, and bone bruise

1.2 Bone Bruise Classification

Mink and Deutsch (1989) were the first to classify bone bruise. Despite many classification attempts, the clear distinction between an existing cortical fracture and hidden fracture that reaches the osteochondral surface has not been fully established. Mink and Deutsch (1989) divided these lesions into four groups: bone bruises, stress fractures, femur and tibia fractures, and osteochondral fractures. On MRI, femur, tibia, and osteochondral fractures are more prominent than the other two lesion groups. Lynch et al. (1989) modified the classification of Mink and Deutsch (1989) to distinguish three types of bone bruises (Table 1.1).

Table 1.1 Bone bruise classification (Lynch et al. 1989)

Type 1	Commonly found on the epiphysis and metaplasia with no cortical change
Type 2	Bone fractures with cortical changes in addition to Type 1
Type 3	Lesions confined to the subcortical bone

Using MRI, Vellet et al. (1991) prospectively investigated 120 patients with acute knee injury. The bone bruises observed were classified as reticular, geographic, linear, impaction, and osteochondral fractures. The most common occult lesions were the reticular type. These were wide lesions spreading to the periphery distant from the cortex or joint surface. The geographic types were lesions that displayed continuous signal changes representing coalescence with subchondral bone. Osteochondral fractures and impact fractures represented intra-articular fractures that reach the joint surface. Difficulties can be encountered with almost all classifications. Since this is a radiologic classification, its prognostic value is unclear; therefore, its use is limited for clinical assessment.

1.3 Bone Bruise Location and Mechanism

The majority of bone bruise and BME research has focused on the knee joint. The reason for this is that MRI screenings are common following potential knee ligament injuries. The mechanisms of injury may be direct, or the bones that form the joint may be in forceful contact with each other. For this reason, bone bruises are common around the knee joint.

A study of 434 patients with acute knee injuries reported a 20% incidence of bone bruises, most in association with ACL rupture (Lynch et al. 1989). With the increased use of MRI in knee ligament injury diagnosis, many bone bruising investigations on lesions are associated with injuries to the lateral collateral ligament, medial collateral ligament, posterior cruciate ligament, and, of course, the ACL (Graf et al. 1993; Kaplan et al. 1992; Murphy et al. 1992; Speer et al. 1995; Tung et al. 1993). Terzidis et al. (2004) examined the MRI of 255 patients with acute knee injuries, and 27.8% of the patients were found to have a bone bruise. Approximately 77% of these patients had sustained an ACL rupture. During the acute period, bone bruises were observed on MRI in more than 80% of ACL ruptures (Rosen et al. 1991; Speer et al. 1995; Spindler et al. 1993). In studies which included patients scanned over a longer period, a smaller incidence ranging from 40 to 56% was reported. In a study by Spindler et al. (1993), it was reported that among knees that displayed a bone bruise, 86% occurred at the lateral femoral condyle. Sixty-five percent of patients with a lateral femoral condyle bone bruise had a matching lateral tibial plateau bone bruise (Spindler et al. 1993). These matching lesions were associated with the valgus knee injury mechanism that injured the ACL. The existence of a “kissing lesion” was also supported by Kaplan et al. (1992) in a study they conducted by examining 100 MRI images of patients with acute ACL injuries. In association with sudden ACL rupture, the injury mechanism that led to bone bruising was blunt trauma from lateral tibial plateau and lateral femoral condyle impact. Chondral defects and intra-articular fractures related to this traumatic injury mechanism were likely precursor to bone bruise formation.

Contusion in the lateral knee compartment correlates with the ACL injury mechanism. After an ACL rupture, the tibia is subluxed in front of the femur, particularly on the lateral side. During this axial and valgus force “pivot shift” injury mechanism, the middle part of the lateral femoral condyle and the posterior aspect of the lateral tibial plateau come into direct impact creating these lesions.

The posterior aspect of the lateral tibial plateau may be structurally weaker than the lateral femoral condyle, and thus lesions of the lateral tibial plateau are more common. Bone bruises may also develop in the knees of patients who experience ipsilateral traumatic hip dislocations. In patients who have sustained hip dislocation, bone bruises may occur at the femoral head or acetabulum with or without associated femoral head or acetabular fracture (Schmidt et al. 2005). Pinar et al. (1997) reported that bone bruises were more common in the medial ankle compartment after ankle ligamentous injuries. Ege et al. (2001) reviewed MRI of 49 patients who presented with knee trauma and reported bone bruises ($n = 33$) as the most common finding. Baker et al. (2016) examined the MRI of professional ice hockey players who experienced a total of 31 ankle injuries. Three different researchers reviewed each MRI for bone bruises and fractures that were not detectable on plain radiographs. The researchers reported that the number of serious bone bruises was eight, seven, and six, respectively, while the fractures were found to be ten, eight, and eight. This suggests greater disagreement among researchers in terms of bone bruise severity at the time of diagnosis (Baker et al. 2016).

The presence of occult bone bruise without cortical bone injury has become a hot research topic. Miller et al. (1998) reported the incidence of bone bruises associated with medial collateral ligament injury to be approximately 45%. Most of the studies on ACL injury and pivot shift movement have focused on the lateral femur condyle. After patellar dislocation, an isolated bone bruise may also occur at the lateral femur condyle (81–100%) and the medial patella (30%) (Wright et al. 2000). Talus and medial malleolus bone bruises are found in 40% of lateral ligament ankle sprains (Dienst and Blauth 2000; Sijbrandij et al. 2000). Bilateral calcaneal bone bruises have also been reported after axial loading. These bone bruises may be accompanied with avulsion fractures associated with the comparatively stronger ligaments than growth plates in childhood (Figs. 1.3 and 1.4).

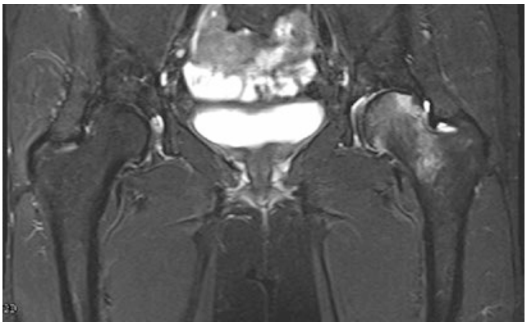

Fig. 1.3 A 60-year-old female with hip pain, no history of trauma. Insufficiency fractures and bone bruise observed at proximal femur with MRI

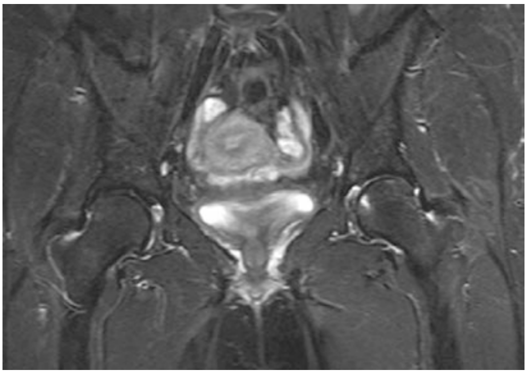

Fig. 1.4 After 12 weeks limited activity, resolution of bone bruise

1.4 Clinical and Histological Findings

It is often difficult to distinguish clinical findings of bone bruises as the traumas leading to their appearance are accompanied with soft tissue lesions and intra-articular injuries. Greater focus on these associated lesions likely contributes to a bone bruise diagnosis not being made during the initial clinic visit. While these may occur due to ACL injury in the knee joint, they can also be associated with other ligament injuries, patellar dislocation, and strains without bone trauma. Bone bruises may also occur after traumatic hip lesions, intracapsular fractures, femoroacetabular impingement, and load distribution impairment from acetabular roof mismatches in congenital hip dysplasia cases. Additionally, ligament injuries at the ankle and in other joints may present as stress fractures, load distribution changes, and ischemic lesions. Due to the wide etiological spectrum of bone marrow lesions, it is often difficult to recognize clinical markers and symptoms. Vincken et al. (2006) observed that patients with bone crush injuries had worse function (in terms of pain-free walking, normal range of motion) and that their activity scores were lower when they were accompanied by intra-articular pathologies. Alanen et al. (1998) followed 95 patients with a 27% bone bruising incidence after inversion ankle injuries. They reported no significant differences in physical activity, limitation of walking, duration of return to work, and clinical scores between patients who had and who did not have a bone bruise.

Valuable histological findings may come from biopsies being taken at different times following joint injury (Fang et al. 2001; Johnson et al. 2000). Following acute knee lesions, Rangger et al. (1998) detected trabecular bone microfractures, edema, and hemorrhage. In a study of Johnson et al. (2000), all patients displayed evidence of articular cartilage and subchondral bone changes following ACL reconstruction. Chondrocytes in the superficial region of the articular cartilage revealed different stages of degeneration. Loss of matrix proteoglycan and osteocytosis were observed in the underlying subchondral bone (Johnson et al. 2000). Fang et al. (2001) reported approximately ten times more intra-articular matrix protein breakdown products in the ACL-injured knee of patients compared with the uninjured knee.

Using in vivo animal models, histological investigations of the effects of blunt trauma on articular cartilage have also been performed (Thompson Jr et al. 1991). It is suggested that bone bruises, which produce no obvious surface deterioration, may lead to chondrocyte loss by creating histological and biochemical articular cartilage surface damage (Donohue et al. 1983; Newberry et al. 1998; Terzidis et al. 2004). There are several mediators associated with bone edema presentation and inflammatory processes that may contribute to articular cartilage degeneration following trauma. Articular cartilage damage can occur from direct lesions or from intra-articular fractures. New tissue at the intra-articular fracture site will be weaker than normal tissue and more fragile to loading forces, particularly shear forces. As a result the risk of joint osteoarthrosis increases (Bretlau et al. 2002; Fang et al. 2001; Kim et al. 2000; Rangger et al. 1998).

1.5 The Natural Course

Bone bruises are lesions that can heal spontaneously. However, the healing time frame is quite variable. This variability is due to the fact that evaluations based on MRI findings often do not correlate with the patient's clinical presentation. It has been reported that patients with bone bruises take longer for symptom resolution, have higher pain scores, take longer to recover normal joint range of motion, and take longer to return to pain-free walking (Johnson et al. 1998; Johnson et al. 2000; Vincken et al. 2006; Wright et al. 2000).

Miller et al. (1998) reported that recovery from bone bruise injuries took 6–12 weeks when bruises were associated with nonsurgically treated medial collateral ligament injuries, displaying a better natural history, than bruises associated with surgically treated ACL injuries. In an ankle injury study using MRI, Pinar et al. (1997) reported that most bone bruises healed by 6–8 weeks, with only one patient displaying persistent bone bruising for approximately 7 months. Sijbrandij et al. (2000) reported that bone bruises at the ankle took longer to recover than bone bruises at the knee. They reported that ankle joint re-injuries and trauma mechanisms might have contributed to the prolonged recovery time (Sijbrandij et al. 2000). Other studies have reported longer recovery time frames. Bretlau et al. (2002) reported that 12% of the patients with acute knee injuries still had MRI evidence of bone bruising after 12 months. Among 13 patients who experienced conservatively treated hip dislocations or fractures, Wikerøy et al. (2012) reported that bone bruises regressed within 2 years. In studying 176 patients following acute knee joint injuries, Roemer and Bohndorf (2002) likewise reported that regression of these injuries took at least 2 years.

In a prospective study that examined the course of post-traumatized knees, Boks et al. (2007) followed 157 bone bruises detected in the femur and tibia of 80 patients. Mean lesion recovery time based on MRI evaluations was found to be 42.1 weeks (Boks et al. 2007). Graf et al. (1993) reviewed patients after an ACL injury and reported that while 71% of those who underwent MRI in the first 6 weeks displayed evidence of bone crushing, they appeared to be resolved 6 months later (Graf et al. 1993).

Vellet et al. (1991) reported that while all reticular structure knee bone bruises regressed, osteochondral sequelae were observed in two-thirds of the geographic-type lesions. Davies et al. (2004) reported that lesion regression occurred in two forms, either from the periphery or toward the joint margin in cases of bone crushing. Slower healing was observed in cases where regression was toward the joint margin. Osteochondral lesions accompanied each of these lesions. In these cases, the rehabilitation progress may need to be slowed or delayed, as the injured joint may be more prone to develop early osteoarthritis. In a case report, Dienst and Blauth (2000) described bilateral calcaneal bone crushing. The patient displayed complete recovery on MRI 6 months after he was restricted from weight-bearing for 4 months.

Although bone fractures have generally been reported to heal within about 6–12 weeks, reported healing times for bone bruises are much more variable. Geographic bone bruises and those with an osteochondral intra-articular component may last for many years. The clinical importance of this is not yet well established. However, chondral defects or intra-articular fractures may prolong bone bruise healing time. The severity of the initial injury, accompanying ligament injuries, the trauma pattern, patient compliance throughout the treatment period, rehabilitation program effectiveness, and the presence of lesions that reach the joint surface are important variables in bone bruise recovery.

1.6 Treatment

The basic approach should be to refrain from heavy weight-bearing loads at the injured area. In the acute phase, cryotherapy, joint elevation, and nonsteroidal anti-inflammatory drugs (NSAID) can be used for symptom relief. Braces can help to support or protect the affected area. Instead of weight-bearing, closed kinetic chain exercises, non-weight-bearing, and open kinetic chain exercises using an isokinetic instrument with range of motion control are preferred. Patients with osteochondral injuries or intra-articular fractures with geographic lesions should have bed rest, refrain from lifting heavy objects, and obtain partial weight bearing through crutch use. The amount of lesion regression and healing time frame should be monitored using serial MRI.

The presence of associated soft tissue and connective tissue lesions in the treatment of bone bruise affects the prognosis and treatment duration. Bone bruises that are identified after low-energy trauma such as knee medial collateral ligament injuries regress more quickly than more central, intra-articular bone bruises located in a primary weight-bearing zone. For patients with internal ligament ruptures or isolated bone crush injuries, it may be sufficient to limit joint loading until clinical findings improve. The situation is different after the high-energy trauma associated with ACL injury (Mankin 1982; Wright et al. 2000). Possible osteochondral injuries associated with high-energy ACL injuries may benefit from delaying full weight-bearing loads until both MRI and clinical evidence of bone bruise regression are observed (Johnson et al. 2000). In patients with ankle injuries, it is appropriate to use a supportive semirigid brace when crutch ambulation is started.

Different BME treatment options have been defined in the literature. The cause of traumatic pain is soft tissue damage, in addition to cortical and intra-articular damage. Nonsurgical treatment including NSAID can be used during the acute phase. Vasodilator pharmacological agents and bisphosphonates can be used in the subacute phase. Surgical core decompression may help reduce the increased intramedullary pressure, which is often associated with long-term pain. Although this application yields good results, it may also increase the risk of fracture and collapse in weight-bearing joints (Hofmann et al. 1993; Leder and Knahr 1995). Nabil et al. (2015) applied three percutaneous cannulated screws in 12 patients with extensive bone bruises in the tibia plateau. Patients were followed up for 15 months, with confirmation that patients complied with rehabilitation exercises and activities including no joint load during the initial 4 weeks post-surgery. On the fifth postoperative week, patients reported that their knee pain was significantly reduced and that they were able to apply full weight-bearing without pain (Ebraheim et al. 2015). This surgical procedure remains controversial, however. Some surgeons perform drilling and decompression treatments for patients with persistent bone bruises. This is followed by rehabilitation exercises and activities without joint loading for the first 6 weeks, followed by partial weight-bearing.

1.7 Conclusion

Despite several studies that have covered this topic, the natural course of bone bruise healing remains controversial and largely unknown. Researchers have focused bone bruise studies on the natural progression, classification, treatment, lesion histology, and whether or not it leads to articular cartilage damage. Bone bruises, which cannot be visualized by conventional imaging methods, can be diagnosed by MRI. Therefore, most studies on this topic rely on MRI evidence of tissue healing status. The reported periods of bone bruise healing are variable and range from 3 weeks to 2 years after the initial injury. Factors affecting this period include the severity of trauma, the type of lesion, the affected bone, and the dimensions of the contusion area, associated soft tissue lesions, post-injury rehabilitation methods, and patient compliance.

Despite these inconsistencies, it appears reasonable to protect the joint from weight-bearing in the early stages after bone bruise, as this is the time associated with microfracture healing.

Clinical and MRI evidence of bone bruise healing coincides with decreased inflammation and edema. Progressive rehabilitation and NSAID or other pharmaceutical agent use may also help decrease patient symptoms.

Studies have reported that bone bruise regression may be related to the patient's age, sporting activity, and type of bone bruise. Treatment is generally focused on limited activity and symptom management. Small bone bruises caused by low-energy trauma usually last for a short time. However, in bone bruises that arise from high-energy trauma, the healing can take several months, or even years. Larger bone bruises associated with high-energy trauma that include a subchondral injury component carry a greater risk of developing osteochondral sequelae leading to osteoarthrosis. In the presence of intra-articular fractures and chondral lesions, recovery and improvement of the activity score take a long time. As a result, it is necessary to undertake longer-term prospective studies to clarify the pathophysiology, natural history of bone bruises, and their relation with osteoarthritis and to determine the correct clinical approach. Even though traumatic causes are frequently responsible for the etiology of bone bruises, other causes should not be overlooked.

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2 Arthroscopic Treatment Vs. Open Surgery in Intra-articular Fractures

T. L. Whipple

2.1 Background

Arthroscopy, as a diagnostic technology, is now over a century old. In 1912, at a meeting of the German Society of Surgeons in Berlin, Severin Nordentoft, M.D., of Aarhus, Denmark, presented his initial experience with visualizing the knee joint with an "arthroscope" he developed incorporating illumination from an incandescent light bulb. Although he used the same device for "cystoscopy" of the urinary bladder, his was the first effort at percutaneous visual access to the interior of a human joint (Jackson 2010).

Professor Kenji Takagi of the University of Tokyo employed a Number 22 French cystoscope to develop more reliable techniques for internal visualization of the knee in cadavers (Watanabe et al. 1969), and Eugen Bircher from Switzerland, while associated with the German Army, developed gaseous insufflation techniques to improve visualization in the knee arthroscopically for diagnostic purposes (Kieser and Jackson 2003). In the United States in 1925, P.H. Kreuscher advanced the diagnostic utility of knee arthroscopy for torn menisci (Kreuscher 1925). Then in 1931 in New York, M.S. Burman expanded at least the theoretical potential of arthroscopy in other joints, using cadaver specimens to explore shoulders, hips, elbows, ankles, and wrists as well as knees (Burman 1931).

To first make diagnostic joint arthroscopy clinically practicable, in 1969 Masaki Watanabe, professor of Orthopaedic Surgery at the University of Tokyo, published an Atlas of Arthroscopy utilizing his acclaimed development of the no. 21 arthroscope (Watanabe et al. 1969). With bright illumination from the affixed incandescent bulb and magnification through a rod lens, the concept of surgical procedures performed under arthroscopic control was readily imaginable. In 1978, Whipple and Bassett (1978) published the first paper describing coordinated portals for accessing intra-articular knee structures with secondary instruments for tissue manipulation, cutting, and removal.

Reduction and stabilization of tibial plateau fractures that disrupted the articular surface of the knee were the first fractures to be so treated by employing the advantages of arthroscopy (Gross and Tejwani 2015). The standards of acceptable reduction of fractured articular surfaces soon changed. It was long taught that a step-off up to 2 mm was satisfactory, although the development of post-traumatic arthrosis too often ensued. More accurate articular surface reduction favored the prognosis for intra-articular fractures. For the tibial plateau, a weight-bearing surface, adjunctive procedures were soon devised to support the restored articular surface, including placing tibial bolts or screws

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immediately beneath the subchondral bone or inserting bone graft into defects beneath the subchondral bone through cortical windows and bone tunnels.

2.2 Articular Fracture Reduction

Intra-articular fractures compromise the prognosis for post-fracture morbidity. Any disruption of the smooth, articular surface will produce some degree of permanent articular scar. Whether the fracture is anatomically reduced or not, any damage to the articular cartilage is irreversible. Articular cartilage lesions do not heal with hyaline cartilage. Fibrocartilaginous articular scars produce increased friction with motion against opposing articular surfaces. Friction erodes the opposing surface, wearing away chards of normal articular cartilage as small, even microscopic, particulate debris in any joint fracture.

Particulate articular cartilage debris migrates to the non-articular synovial recesses of a joint where it is entrapped in the synovial villi of the joint lining. This is the primary basis for inflammatory, symptomatic arthrosis. The other basis derives from the loss of articular cushion normally provided by the smooth articular cartilage. Load forces or compression of a joint surface is transferred unmitigated to the subchondral bone, producing bone edema and marginal osteophyte formation. Articular fracture treatment, therefore, seeks to minimize articular scar formation. Lesser step-off heights and narrower fracture line separations are key to the care of these fractures. These objectives are subject only to visual observation during fracture reduction. Fluoroscopic fracture reduction has merit, but the articular cartilage is radiolucent, and its smoothness can only be inferred from fluoroscopic or radiographic views of reduced intra-articular fractures.

Direct, three-dimensional visualization of the articular surface can be achieved either with open joint exposure or arthroscopic assessment. Ultrasonography can show joint cartilage thickness, but it provides only a two-dimensional image. Thus ultrasound is of limited value for the assessment of articular surface restoration during fracture reduction.

The soft tissues surrounding a fractured joint, both the extrinsic ligaments and the joint capsule, constrain the degree to which fractured articular surfaces can be exposed in the course of open surgical reduction. Small incisions restrict illumination from external light sources, and visualization of fracture lines that extend to deeper or remote portions of articular surfaces is often suboptimal. For these reasons, introducing a light source together with a magnifying lens, even lenses equipped with angled, prismatic capabilities, will afford the better direct visualization of a fractured articular surface during attempts at reduction of the fracture and restoration of the smoothness of the joint surface. Because arthroscopic visualization is so good, compared with joint visualization during open reduction techniques, a new standard of care for articular fractures has evolved. Previous acceptance or “adequacy” of 2 mm step-offs on the articular surface is inadequate by current standards of care.

2.3 Associated Soft Tissue Injuries

Articular fractures do not necessarily occur in isolation. Angular forces and rotational forces, as opposed to direct compression forces, will often injure the periarticular soft tissues. Again, the optimum opportunity to repair traumatically induced tissue disruption is in the acute stage. Just as bone fractures are most easily reduced before early scarification occurs, so too is it easiest to identify and repair the periarticular ligaments, capsule, and articular cartilage structures that may be disrupted from forces that produce the bone fracture.

All diarthrodial joints are stabilized by systems of ligaments and by the collagenous joint capsule. Some joint sockets or concavities are deepened by circumferential fibrocartilage lips or labrums to provide greater stability to the opposing convex joint surface. The shoulder labrum and the hip joint acetabular labrum are such examples. Clinical appreciation of injuries to any of these structures is first suspected from localized tenderness to palpation and passive stability testing of the joint during examination.

In the presence of an articular or periarticular joint fracture, localized tenderness is unreliable, and stability testing is not well tolerated to indicate concomitant soft tissue injury. Thus, many associated soft tissue injuries may be overlooked in acute fracture stages. MRI imaging will disclose the presence of periarticular soft tissue injuries. Arthroscope use, if practicable, enables the visual inspection of periarticular structures for hemorrhage, rupture, detachment, delamination, or any other indication of soft tissue trauma. This may be both expedient and economical for identification and initial treatment of associated joint injuries.

In addition to intrinsic ligaments, many extrinsic joint ligaments that merge or blend with joint capsule tissue fibers can be seen directly via arthroscopic inspection. Such examples in the knee are the medial collateral, the oblique popliteal, and the arcuate popliteal ligaments. Extrinsic ligaments of the shoulder that are at least partially visible arthroscopically include the superior, the middle and the inferior glenohumeral ligaments which may be stretched or avulsed in association with glenoid surface fractures or fracture dislocations of the shoulder. In the wrist, extrinsic ligament injuries that commonly coincide with distal radius articular fractures include the radioscaphocapitate ligament and the ulnocarpal ligaments.

Intrinsic ligaments frequently injured in association with articular fractures include the anterior and posterior cruciate ligaments of the knee and the meniscotibial ligaments. In the wrist, the intrinsic scapholunate ligament or the lunotriquetral ligaments may be acutely repaired at the time of articular fractures of the distal radius to prevent subsequent carpal instability after the fracture heals.

The glenoid labrum in the shoulder and the acetabular labrum of the hip are at risk coincident with fracture dislocations or fracture subluxation injuries of the shoulder or the hip, respectively. In the elbow, injuries to the ulnar collateral ligament often coexist with articular fractures of the radial head; and in the ankle, tibial plafond fractures may be associated with medial deltoid ligament or anterior talofibular ligament rupture. Knowledge of associated soft tissue injuries early in the treatment effort by virtue of arthroscopic examination can improve the ultimate prognosis for full return to function. This may also expedite the post-injury rehabilitation program with consideration of the soft tissue injuries.

2.4 Loose Bodies

Marginal chip fractures from any bone's joint surface are, by definition, intra-articular fractures. Often marginal chip fractures are attached either to a joint's primary stabilizing ligaments and represent avulsion fracture injuries containing a fragment of the joint's articular surface. Arthroscopic monitoring of precise, anatomic reduction of these fracture fragments while they are pinned or screwed back into place will ensure the best restoration of joint stability or capsular accommodation for the ultimate restoration of full joint range of motion.

Some chip fractures may occur from the surface of a joint exclusive of any peripheral soft tissue attachment. These osteochondral chip fragments may remain in place, as in pilon fractures of the ankle, tibial plateau fractures of the knee, or fractures of the hip. Or they may float free within the joint as loose bodies. While such fracture fragments may be reduced and stabilized or retrieved for removal from the joint through arthrotomy, arthroscopy is almost always less intrusive and less disruptive, often even more precise, than releasing or incising the joint capsule for the same fracture treatment objective.

Notably, arthroscopic treatment of intra-articular chip fractures has even gained popularity among veterinarians for reduced surgical trauma and more expedient rehabilitation of equine injuries to the carpus (Shimozawa et al. 2001).

2.5 Articular Degenerative Changes

Finally, asymptomatic but pre-existing degenerative changes of articular cartilage prior to the occurrence of an articular fracture will guide treatment decisions related to immobilization, weight-bearing, and ultimate partial impairment. Degenerative, thin articular cartilage will enjoy disadvantaged recuperation potential after an intra-articular fracture. Prognosis for fracture healing and joint rehabilitation are important in consideration or recommendation of primary joint replacement or primary joint arthrodesis following an articular fracture. These concerns pertain especially to articular fractures of the tibial plateau, fractures of the acetabulum, or distal radius fractures when an early arthroscopic examination of the fractured degenerative surface can bolster decision-making for the early treatment of intra-articular fractures.

2.6 Conclusion

In summary, there are numerous advantages afforded by the option of arthroscopic examination and, whenever possible arthroscopic treatment, of many intra-articular fractures. Soft tissue disruption via iatrogenic surgical arthrotomy may unnecessarily inflict additional trauma to the patient or to the affected joint. Better illumination together with magnification provides more precise reduction of intra-articular fracture fragments, minimizing articular scar formation and raising the bar for standards of care of articular surface fractures. Angled lenses on arthroscopes permit visualization around difficult corners and over articular margins into joint recesses for the retrieval of loose bodies or assessment of pericapsular extrinsic ligament ecchymosis. Fracture reduction for articular surfaces by arthroscopic observation preserves soft tissue integrity and reduces associated soft tissue stiffness during joint rehabilitation after fracture healing.

Finally, appropriate emphasis should be placed on the importance of minimizing the cosmetic effect of fracture treatment. Patients may never see their fractured bones or even their x-rays, but they will always see permanent scars from incisions utilized for fracture reduction and fixation. These are visible reminders of not only the injuries they sustained but also of the surgeon—by whom and when, but not why—their visible surgical scars were inflicted.

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3

Intra-articular Fractures: Principles of Fixation

Samarth Mittal and Ravi Mittal

3.1 Introduction

Intra-articular fractures cause damage to articular cartilage, and this can create impaired joint function, disability and early post-traumatic osteoarthritis (PTO) (Dirschl et al. 2004). Sir John Charnley (2003) in the book *The closed treatment of common fractures* advocated conservative treatment of fractures. Even Abraham Colles (1814) while describing Colles' fracture said "One consolation only remains, that the limb will at some remote period again enjoy perfect freedom in all its motions, and be completely exempt from pain; the deformity, however, will remain undiminished throughout life." Many others have shared the same ideology (Neer et al. 1967; Stewart et al. 1966). However, this was at a time when the knowledge of modern orthopaedics was still in its early period with very limited availability of implants. It was soon realized that all intra-articular fractures could not be managed nonoperatively. Sir James Paget said that "There are, I believe, no instances in which a lost portion of cartilage has been restored or a wounded portion repaired with new well formed cartilage in a human subject"(Peltier 2007). With multiple advances and enhancement in the knowledge of orthopaedics, the treatment of intra-articular fractures has come a long way.

3.2 Classification

Classification of intra-articular fractures is important not only to characterize a fracture pattern but also as a guide to treatment and to suggest an approximate prognosis (Garbuz et al. 2002). Many different classification systems for different articular fractures have been proposed with each one of them having their own pros and cons. However, after the foundation of the AO group in 1958, Maurice E. Müller developed a universal classification system for all fractures for the sake of simplicity around the globe (Müller et al. 1991). He believed "A classification is useful only if it considers the severity of the bone lesion and serves as a basis for treatment and for evaluation of the results". According to this classification, all long bones were numbered 1 (humerus), 2 (radius and ulna), 3 (femur) and 4 (tibia and fibula) (Fig. 3.1). Then each of these bones was divided into three segments which were also numbered 1 (proximal), 2 (diaphyseal) and 3 (distal).

Then fractures of each of these three segments are divided into three types (A, B, C) with further subgroups into another three types. This generates a hierarchical organization in the form of triads (Fig. 3.2).

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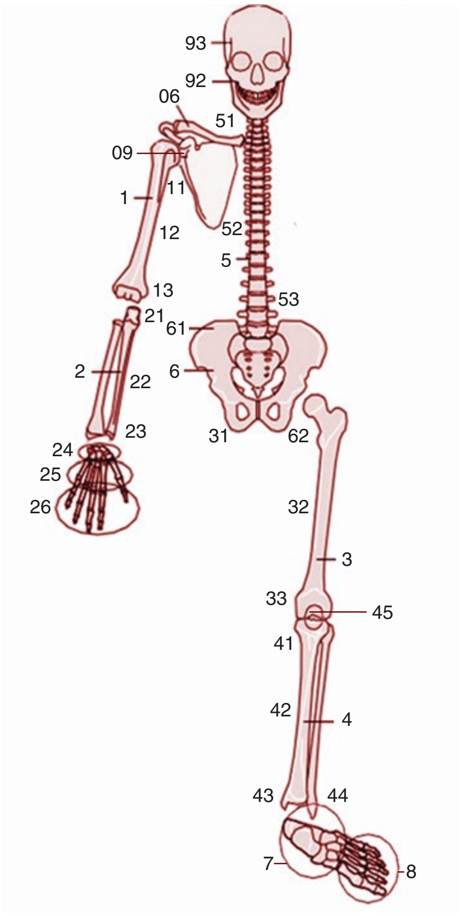

Fig. 3.1 Orthopaedic Trauma Association (OTA) system showing numbering for location of fracture and the three bone segments with a location (1 proximal, 2 diaphyseal and 3 distal) Müller et al. 1991)

The important feature of this classification system lies in the principle that it places fractures in an increasing severity order keeping into view the fracture's morphological complexity and the inherent difficulties in their treatment and prognosis.

According to the AO/ASIF classification, the fractures that fall under the category of intra-articular fractures include fractures of segments 1 and 3 (proximal and distal) with a subcategory B and C.

Even though they may slightly vary from joint to joint, broadly they can be understood with the help of example of fractures of the distal femur and distal radius as (Figs. 3.3, 3.4, 3.5):

B1: Partial articular with fracture in sagittal plane
B2: Partial articular with fracture in frontal plane (Fig. 3.3) or fracture on opposite side as B1 (Fig. 3.4)
B3: Partial articular with fracture in frontal plane only (Fig. 3.3) or in both frontal and sagittal plane (Fig. 3.4)

C1: Articular simple, metaphyseal simple
C2: Articular simple, metaphyseal multifragmentary
C3: Articular multifragmentary

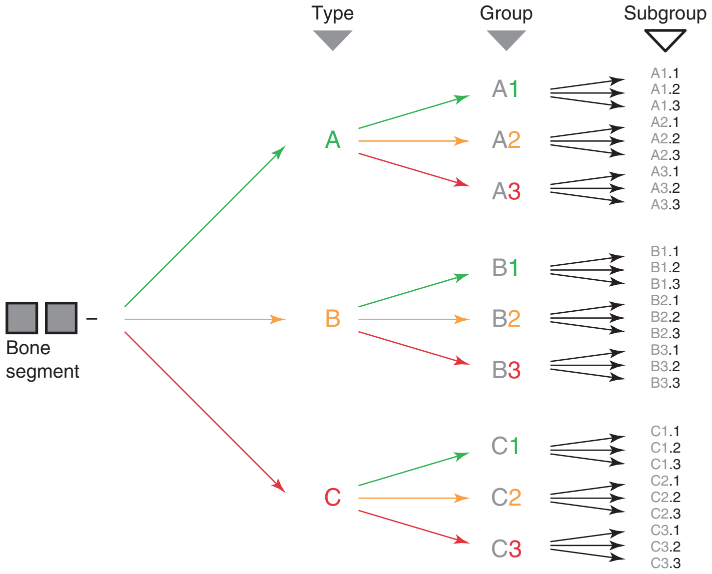

Fig. 3.2 Each fracture fragment is classified into three morphological types A, B and C. Each of these types is further subdivided into three groups A1, A2 and A3; B1, B2 and B3; and C1, C2 and C3 (Müller et al. 1991)

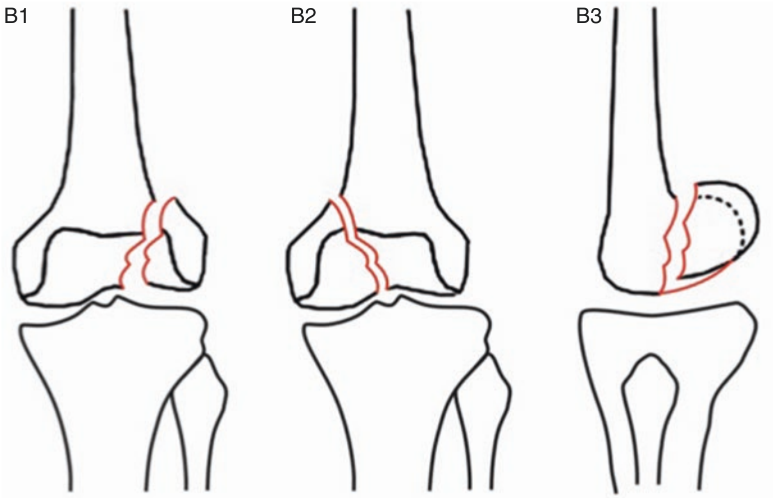

Fig. 3.3 Partial articular fractures of distal femur

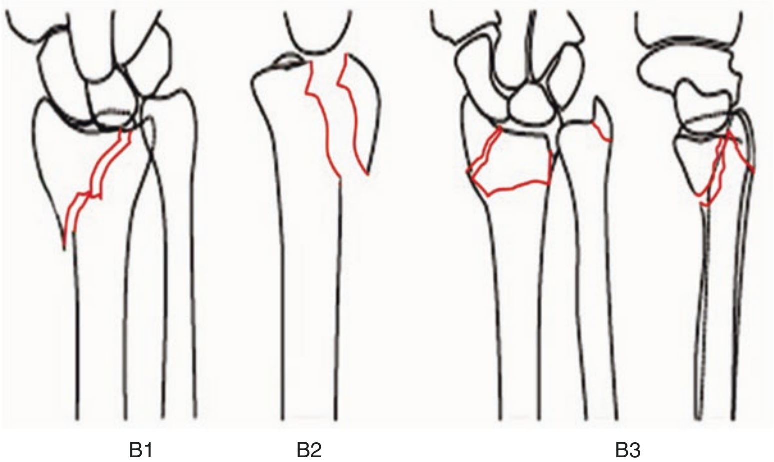

Fig. 3.4 Partial articular fractures of distal radius

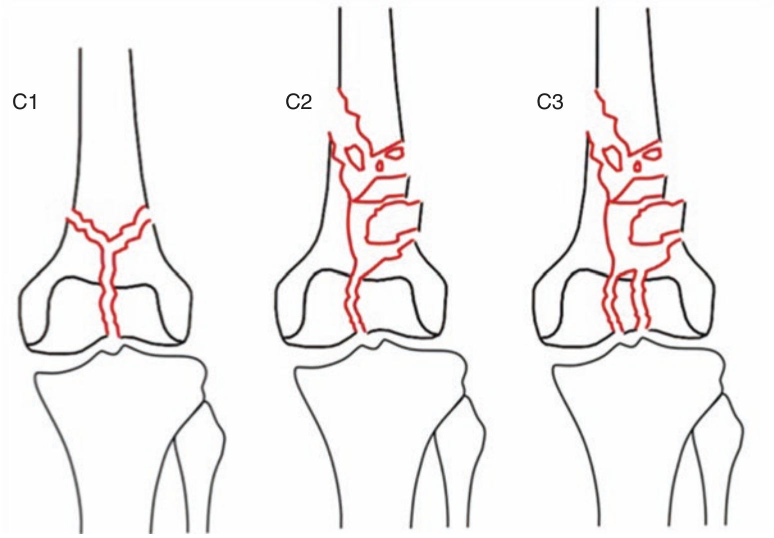

Fig. 3.5 Complete articular fractures of distal femur

3.3 Unique Features of Intra-articular Fractures

Synovial joints are articulating surfaces lined by avascular, elastic and resilient hyaline cartilage which helps distribute joint stresses and forces onto the subchondral bone. Due to its aneural nature with lack of blood and lymphatic supply, it takes its nutrition from surrounding structures through diffusion. Any damage to the articular cartilage leads to healing through fibrocartilage formation which has much different mechanical and structural properties as compared to normal hyaline cartilage.

Joints are stabilized by the morphology of the bones and joints and accompanying ligaments and actively, by the muscles crossing the joint. For maintenance of a delicate balance of healthy and stable joint, repetitive loading and motion of the joint are a must along with maintenance of its stability. Any factor that disturbs this balance such as trauma or inflammatory diseases may lead to arthritis of the joint. Even though the articular cartilage on both the joint surfaces may be smooth, highly incongruous joint surfaces may limit the contact surface area needed for full range of motion.

Interestingly, the thickness of articular cartilage varies considerably from joint to joint. There is variation in its thickness even within the same joint at different places (Shepherd and Seedhom 1999). Shepherd and Seedhom (1999) showed the more congruent joints such as the ankle had much thinner articular cartilage than more incongruent joints such as the knee. They also derived a positive correlation between the thickness of articular cartilage and the largeness or heaviness of an individual. Thus incongruent joints in larger individuals tend to have a thicker articular cartilage.

3.4 Imaging of Intra-Articular Fractures

Among the basic radiological investigations, simple anteroposterior and lateral radiographs of the involved joint with one joint above and below the fracture site are required. However, in most joint injuries, these are usually not sufficient. The addition of traction may serve as a very useful tool especially in cases of proximal femoral and tibial plafond fractures. With the development of CT scans and 3D reconstruction, it became easier to understand complex articular fractures. Even with CT scans, the principle of "Span- Scan- Plan" should be kept in mind. This suggests that CT scans should be ordered only after spanning the fracture with an external fixator. This enables the acquisition of better information for the planning of the reduction and fixation of complex fractures, especially those around the knee and ankle.

The use of intraoperative fluoroscopy has helped surgeons in achieving and assessing intraoperative fracture reduction. Tornetta and Gorup (1996) found out that use of CT scans in cases of pilon fracture reduction planning gave additional information in 82% patients and led to a change in surgical plan in 64% patients. With further intraoperative 3D fluoroscopy and navigational advancements, the surgeon will have additional surgical planning tools (Kendoff et al. 2008, 2009; Wong et al. 2015). Intraoperative CT scan use has been limited due to the high costs and radiation involved with the procedure. Recent studies to assess articular cartilage degeneration using T1-rho MRI images have shown promising results; however, its application for assessing damage to acutely damaged articular cartilage is still pending (Guermazi et al. 2015; Rakhra et al. 2012; Wang and Regatte 2014).

3.5 Basic Principles of Management of Intra-articular Fractures

Sir John Charnley proposed early joint freedom of movement, and its perfect anatomical restoration following intra-articular fracture could only be achieved by internal fixation. However, due to lack of availability of refined implants in his era, he was not a strong proponent of internal fixation of articular fractures. With the development of innovative implant devices, anatomical reduction with absolute intra-articular fracture stability became much more likely. This has allowed for the early joint range of motion that has become the dictum of management of such injuries.

In the book, *The Rationale of Operative Fracture Care*, Schatzker and Tile (2005) gave principles of treatment of intra-articular fractures which are:

- Reduction of articular surface should be anatomical and atraumatic.
- Fixation of articular fragments should be stable.
- Deformity should be corrected in the axial plane.
- The metaphysis should be buttressed.
- Early range of motion should be started.
- Since it cannot remodel, articular cartilage incongruity leads to osteoarthritis.

It is imperative to understand that intra-articular fractures discussed in this book differ from their diaphyseal counterparts in a sense that they require fixation by absolute stability instead of relative stability as in case of diaphyseal fractures. Absolute stability can be achieved by using interfragmentary lag screw and tension band principles, while relative stability is usually achieved by methods such as external fixators, bridged plating techniques and intramedullary nails. It should also be noted that diaphyseal fractures only require maintenance of length, rotation and axis in their reduction, whereas intra-articular fractures require an anatomical reduction in order to obtain a good outcome.

Principle methods for reducing fractures include:

1. Closed reduction: wherein fracture reduction is achieved without opening the fracture ends
2. Open reduction: wherein fracture reduction is achieved after opening the fracture fragments
3. Direct reduction: wherein fracture reduction is obtained by directly manipulating fracture fragments either by hands or by instruments
4. Indirect reduction: wherein fracture reduction is obtained by indirect manipulation of the fracture fragments using forces away from the fracture ends without opening the fracture fragments, usually using ligamentotaxis

Moreover, the above methods can be used to achieve the and visualize reduction using:

1. Direct visualization: For instance, reduction of the radius and ulna in a simple both bone forearm fracture.
2. Fluoroscopic guidance: For instance, reduction of most intra-articular fractures.
3. Arthroscopic assistance: This is the most recent method to appreciate intra-articular fracture reduction wherein joint surface restoration is confirmed under direct viewing.

Even with advancement in intra-articular fracture management knowledge, the principles outlined by Schatzker and Tile (2005) more or less still hold true. In an era when the knowledge of intra-articular fractures is far from complete, Hahn (2004) helped to compile the latest knowledge and developed the following basic principles of intra-articular fracture management.

1. Anatomic intra-articular reduction
2. Restoration of joint congruity
3. Mechanical alignment restoration through stable fixation
4. Early joint movement and mobilization
5. Avoidance of surgical and nonsurgical complications as far as possible

Deviation from these principles can cause post-traumatic osteoarthritis (OA). While its exact aetiology is still a question, occurrence of post-traumatic osteoarthritis (OA) is believed to occur through three different mechanisms (McKinley et al. 2004).

1. Damage to articular cartilage through direct impact trauma (Ewers et al. 2001; Marsh et al. 2002; McKinley et al. 2004; Newberry et al. 1998; Thompson et al. 1991; Sanders et al. 1993)
2. Increased chronic articular cartilage contact stress from residual articular cartilage incongruity (Lefkoe et al. 1993; Llinas et al. 1993; Lovász et al. 1998; McKinley et al. 2004)

3. Abnormal articular cartilage loading associated with residual joint instability (Delamarter et al. 1990; Lansinger et al. 1986; Lovász et al. 2001; McKinley et al. 2004)

There is conclusive clinical evidence linking residual joint laxity following intra-articular fracture to post-traumatic osteoarthritis (Daniel et al. 1994; Dedrick et al. 1993; Delamarter et al. 1990; Lansinger et al. 1986). However, there is controversy over whether incongruity definitely leads to post-traumatic osteoarthritis with evidence both supporting (Lansinger et al. 1986; Lovász et al. 1998) and refuting (Honkonen 1995; Llinas et al. 1993; Stevens et al. 2001) this theory.

In combination with continuous passive joint motion application, Mitchell and Shepard (1980) reported poor results following distal femoral condyle fractures in rabbits that had incomplete reduction and unstable fixation and good results in rabbits with anatomic reduction with stable fixation. Based on this finding, they linked good results to anatomic reduction, stable fixation and early joint movement after fracture fixation.

In cases where the lesion step-off was less than the thickness of the articular cartilage in the region, Llinas et al. (1993) reported a tendency of articular cartilage to remodel in order to restore congruity. They associated poor outcomes with nonanatomical fracture reductions with larger lesion step-offs.

At 5-year follow-up, Rasmussen (1973) in a series of patients with 204 tibial plateau fractures showed good results in 87% of cases irrespective of the articular reduction as long as coronal plane stability was re-established. Longer follow-up of 20 years showed that even patients having more than 1 cm depression had 90% good results if the knees were stable. This study concluded that articular depression was well tolerated in fractures around the knee while residual laxity was not.

McKinley et al. (2004) postulated that different joints tolerate incongruity of joint surface differently; however, residual laxity was poorly tolerated by all joints. They further concluded even though residual laxity was poorly tolerated by hip, knee and ankle joints, the knee joint was different from hip and ankle joints in tolerating incongruity to a greater extent.

The reason for greater incongruity tolerance by some joints more than others was given by Dirschl et al. (2004). They concluded that this tolerance was dependent on multiple factors such as the general morphology and geometry of the joint and thickness and modulus of the joint cartilage. This was substantiated by Huber-Betzer et al. (1990) who showed that with increasing modulus of cartilage and decreasing cartilage thickness, step-offs caused an increase in the maximal local contact stress. Dirschl et al. (2004) described the reason for poor results for intra-articular fracture cases treated with good anatomical reduction and stability as the high amount of cartilage injury by the acute impact to the cartilage at the time of the injury. The prevalence of good functional results despite radiographic appearance of post-traumatic osteoarthritis in patients was also highlighted in their study.

There is very little understanding of the specific cellular and biomechanical mechanisms that are triggered by the trauma leading to post-traumatic osteoarthritis. Olson and Guilak (2006) described the lack of this knowledge as a “black box”. They highlighted a current lack of an effective application of articular cartilage repair techniques in intra-articular fracture management. A lack of prospective study-based evidence has led to widely diverse intra-articular fracture and joint arthritis management strategies.

3.6 Importance of Step-Offs/Gaps

Residual articular surface incongruities following intra-articular trauma are referred to as gaps or step-offs. These step-offs create an increase in localized peak mechanical pressures, and contact stress increase on the joint surface that leads to post-traumatic osteoarthritis. These locally increased contact pressure and stresses are directly proportional to the size of the step-off. Since intra-articular fracture joint step-off tolerance is a reverse function of the cartilage thickness of the joint (Brown et al. 1988), it is generally not possible to reach an acceptable step-off limit. However, traditionally step-offs of less than 2 mm are considered acceptable (Dirschl et al. 2004). The peak local stresses on the cartilage at these step-offs were shown to increase with increased modulus of articular cartilage and decrease in articular cartilage thickness (Huber-Betzer et al. 1990).

Another problem that is encountered is the absence of an accepted tool to measure step-offs (Martin et al. 2000). It has been shown that there is about ±12 mm of interobserver variation in quantification of articular depression in the acute fracture stage of tibial plateau fractures using plain radiographs (Martin et al. 2000). Not only this, in postoperative healed fracture patients, the intraobserver variability in measurement of articular displacement was found to be ±3 mm when the maximum range of displacement was just 4 mm leading to an error margin of as high as 75% between observers (Kreder et al. 1996).

Experimental studies in animals have shown that if the size of these step-offs is not large enough to cause joint malalignment or instability, then they have a good potential to heal. Llinas et al. (1993) and Lovász et al. (1998) in their experiments in rabbits showed that 1 mm step-offs in the distal medial femoral condyles of rabbits completely healed within 12 weeks with formation of articular cartilage by chondrocytes. Mitchell and Shepard (1980) showed in rabbit model that articular cartilage healed by hyaline cartilage formation in cases where accurate fracture reduction was achieved with sufficient fracture site compression. However, fibrocartilage healing was evident when accurate anatomical fracture reduction was achieved without compression.

3.7 Healing of Articular Cartilage

Articular cartilage contains an extracellular matrix with water and a macromolecular framework made up of proteoglycans and collagens (Buckwalter 1998; Buckwalter and Lane 1997; Buckwalter and Mankin 1998). The tensile strength and form of the articular cartilage can be attributed to the collagens, while the properties of resilience, durability and stiffness to compression are provided by the complex interaction of water with the aggregating proteoglycans. Whenever, the cartilage is loaded, the fluid movement inside it helps to dampen and distribute the load (Buckwalter 1998). However, this is true in slow loading of the cartilage with time to deform with the fluid movement thereby decreasing the force applied to its core structure. But, when the cartilage loading is sudden, there is more stress on the macromolecular framework of the cartilage which may even lead to its rupture and cell death. Therefore, it is for this reason that sudden unexpected abnormal loading of the joint may lead to greater articular cartilage damage (Buckwalter 1998).

Response of articular cartilage to damage depends on the type of injury (Buckwalter 1998):

(a) *Chondral damage without visible tissue disruption*: Such injuries do not present with any specific symptoms except pain. Most of the radiologic investigations and even joint arthroscopy are usually normal although MRI scan may identify such injuries. Such injuries have a good possibility of healing by cell proliferation within the cartilage if the basic structural matrix of the cartilage remains intact. However, if the basic structural matrix is damaged, then it may lead to articular cartilage degeneration.

(b) *Disruption of articular surface alone without involvement of subchondral bone:* Such injuries include chondral ruptures or flaps, and such injuries may present with symptoms such as synovitis and effusion or with mechanical symptoms. There is some cell proliferation as a local response, however, it is unable to form new tissue that can fill the cartilage defect. Such lesions may remain or may progress to articular cartilage degeneration depending on the size and location of the lesion within the joint and the stability and alignment of the joint.

(c) *Damage to articular cartilage along with subchondral bone:* Since the subchondral bone is vascular, such injuries result in formation of a fibrin clot, inflammation, new cell proliferation and new bone and cartilage production. These lesions usually present with symptoms of synovitis, with joint effusion or with mechanical symptoms. Depending on the site and size of lesion as well as the stability and alignment of the involved joint, these injuries may remain, healing with hyaline cartilage-like tissue formation, or may begin to undergo degeneration. Intra-articular fractures belong to this category of injury.

3.8 Conclusion

Articular fractures are complex injuries which require application of basic principles and skills in their management in order to reduce their complications. Coupled with the availability of the latest implants and technology such as newer locking plates, 3D CT scans, 3D fluoroscopic and CT-guided navigation and the partial understanding of the significance of articular congruity, joint stability and early joint movement, we are still in the nascent stages in the process of completely understanding these injuries. Multiple factors like energy of trauma, fracture reduction and fixation, joint stability and articular cartilage thickness and elasticity affect the final outcome. More prospective evidence from multicentre clinical trials is required to solve the remaining questions and clinical problems related to these injuries.

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4

Intra-articular Fractures: Philosophy of Minimally Invasive Fixation

Haluk Hayri Öztekin and Hakan Boya

4.1 Minimally Invasive Fixation

Traditional fracture treatment methods often depend on an open approach to achieve and maintain anatomical fracture reduction and fixation using plates or other devices. Associated with this application, periosteal tissue is generally peeled off which compromises bone vascularity (Rhinelander 1974a). Consequently, based on the injury of blood supply, it is essential to monitor delayed fracture site union and nonunion. To avoid these potential problems in diaphyseal and meta-diaphyseal comminuted fractures, soft-tissue attachments of fracture segments can be protected by using minimally invasive and bridging plate techniques (Cole et al. 2003; Duncan and Weiland 2001; Egol et al. 2005; Gotfried 2002; Krettek et al. 2001; Mast and Ganz 1989; Perren 2002; Russell and Smith 1999). Minimally invasive surgery has become an accepted practice in all fields of surgery, including the treatment of comminuted fractures (Bhandari and Shaughnessy 2001; Duncan and Weiland 2001; Egol et al. 2005; Garfin and Reilley 2002; Kankate et al. 2001; Perren 2002; Rhinelander 1974b; Russell and Smith 1999; Schütz et al. 2001; Shuler et al. 1995). Moreover, orthopedic surgeons have used techniques to protect fracture biology for many years (Kregor et al. 2001). These concepts have included use of bridging plates, closed intramedullary nailing, external fixation, cannulated screws, and, more recently, percutaneous plating (Apivatthakakul and Arpornchayanon 2002; Farouk et al. 1997, 1999; Kankate et al. 2001; Krettek et al. 1997, 2001; Mast and Ganz 1989; Remiger and Engelhardt 2006; Rhinelander 1974a, b; Ruedi et al. 1998). The common feature of all biological fixation methods is protection of the soft tissues that are connected to small fracture fragments. In fracture treatment, anatomical reduction of the articular surface should be obtained, stable fixation should be provided by implants, the bone blood supply should be preserved, and early joint motion should be initiated as soon as possible. As biologic fixation methods improve, bone blood supply preservation should improve likewise (Brandt et al. 2002; Cole et al. 2003; Gotfried 2002; Krettek et al. 2001). Indirect fracture reduction techniques that avoid unnecessary damage to the bone vascularity improve fracture union rates (Kregor et al. 2001). Restoration of bone length and rotation are the main concerns in diaphyseal long bone comminuted fracture management. Use of locked intramedullary nail fixation helps to protect the biological aspects of fracture healing while overcoming these challenges. Minimally invasive fixation enables better bone and soft-tissue protection (Takeuchi et al. 2002). Use of

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a small incision and soft-tissue envelope, with minimal periosteal stripping, helps prevent blood supply injury and protects the nerves (Rhinelander 1974a). This is in fact mandatory for rapid healing and prevention of complications. New implant designs have been developed to help achieve this using both traditional, locking plates and minimally invasive fixation techniques. The aforementioned applications are for diaphyseal and metaphyseal comminuted fractures. However, another dilemma in fracture treatment is "intra-articular fractures," especially comminuted ones. When inappropriately treated this fracture type will inevitably lead to catastrophic results.

4.2 Intra-articular Fractures

4.2.1 Description

Intra-articular fractures that extend to the articular surface are often associated with some degree of articular cartilage damage (Fig. 4.1). Despite its limited repairing capacity, articular cartilage

Fig. 4.1 (**a**–**c**) Seventeen-year-old female patient. Right knee radiographs show a displaced anterior eminentia fracture in 2007 (**a** and **b**). In MRI large bony fragment and bone marrow edema are clearly seen (**c**)

can remain viable after blunt trauma (Rhinelander 1974a; Thakur 2015).

4.2.2 Problems Related to the Treatment

Problems related to improper intra-articular reduction and lack of early postoperative controlled joint motion may include instability, impaired joint motion and mechanics, fibrosis, and osteoarthritis (Thompson et al. 1991). This may lead to excessive scar tissue formation due to a hyperactive inflammatory healing response. Poor fracture immobilization may also lead to excessive fibrous tissue formation. Following open surgery, the potential for excessive scar tissue formation is even greater. To overcome joint stiffness, immediate motion is mandatory.

4.2.3 Treatment Planning

There are a few essential rules in the treatment of intra-articular fractures. These include joint surface anatomy restoration and fixation that is sufficiently stable to allow for early postoperative mobilization.

Achieving an effective reduction of impacted intra-articular fragments with closed manipulation and traction is unlikely. The displacement of articular fragments may contribute to permanent joint instability. Anatomic reduction should be provided to restore articular congruity (Fig. 4.2). Stable internal fixation is needed to enable controlled early postoperative motion. Bony defects at the metaphyseal area, which supports the articular cartilage surface, should be grafted to prevent articular fragment displacement.

It may not always be possible to achieve these goals using conventional open surgery. The magnitude of soft-tissue damage that may be created is a key component in selecting the surgical approach. Restoration of anatomical ligament attachment relationships is vital. Traction (manual or mechanical) of the limb is generally effective to achieve anatomic articular fragment reduction through their ligament attachments. To preserve blood supply, extensive stripping of any capsular and/or soft-tissue attachments of cortical/articular fragments should be avoided. Minimally invasive fixation using fluoroscopy or arthroscopy can help to overcome these drawbacks (Egol 2004).

Advantages of this philosophy in managing comminuted intra-articular fractures include (Thakur 2015):

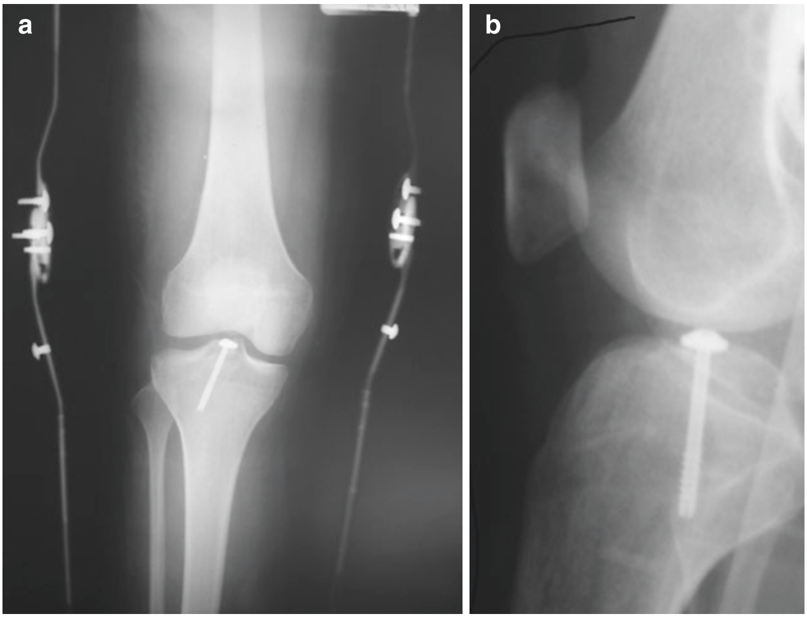

Fig. 4.2 (**a**, **b**) Postoperative images after immediate arthroscopic-assisted minimally invasive fixation of anterior eminentia fracture with a cannulated screw and washer

- Smaller incisions, less muscle dissection, decreased disruption of blood supply to the bone, reduced fracture hematoma disruption, faster fracture healing, and quicker patient recovery
- Avoidance of open surgical trauma to non-injured fracture site components by preserving bone, periosteum, and soft-tissue structure vascularity
- Less intra-articular fibrosis and scar tissue
- Less postoperative pain and discomfort
- Preservation of soft tissues that stabilize the joint (capsule, ligaments, etc.)
- Greater ability to implement safe, early controlled postoperative motion

4.3 Conclusion

Biological aspects of fracture healing should be emphasized during treatment planning. Protection of soft tissues is vital for bone vascularity and union. Minimally invasive techniques and specially designed implants will help the surgeon achieve these goals. This philosophy is indispensable for the surgical management of comminuted metaphyseal and diaphyseal fractures and for intra-articular comminuted fractures. Precise anatomic reduction and absolute bone-implant construct stability are essential treatment goals. Metaphyseal bone defect grafting to prevent joint surface collapse and postoperative controlled early motion are keys to treatment success.

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5

Biologic Solutions for Articular Cartilage Healing

F. Perdisa, L. Andriolo, R. De Filippis, E. Kon, and G. Filardo

5.1 Introduction

Managing post-traumatic defects of the articular knee surface, as well as degenerative conditions derived from intra-articular fractures, is a challenge for the orthopedic surgeon. In fact, early degenerative changes, starting from the affected compartment, will eventually involve the whole joint, leading to osteoarthritis (OA). The risk of post-traumatic OA (PTOA) following significant joint trauma has been reported to be as high as 75%, whereas articular fractures can increase the risk by more than 20-fold (Goetz et al. 2015; Schenker et al. 2014). Biomechanical, metabolic, and biological changes following joint injury may initially affect tissue homeostasis, resulting in accelerated loss of the articular cartilage surface leading to end-stage OA. Articular cartilage has limited regenerative potential, due to the lack of vascularity and nerve supply. Therefore, even small isolated injuries of the articular cartilage of the knee will heal with difficulty, and the higher mechanical stress on the lesion's edge poses the risk of further degeneration (Gill et al. 2001; Jansen et al. 2013; Weiss et al. 2003).

Therefore, articular fracture treatment goals generally include highly accurate reduction and stable fixation, in order to provide restoration of the damaged joint surface that would be as close as possible to the original anatomy. Indeed, disruption of any joint component can result in altered load distribution, and any fragment displacement is associated with joint surface gaps or incongruences that will have secondary effects on knee motion and biomechanics (Llinas et al. 1993). Moreover, inflammatory responses following injury can lead to an extensive development of fibrosis, which can worsen following inappropriate surgical or mobilization management (Schatzker 1988). Whereas the tolerable amount of articular surface displacement (steps or gaps) has not been determined yet, the importance of anatomical joint surface restoration and the correct axis are considered mandatory to provide successful long-term outcomes after articular fractures (Matta 1996; Schatzker and Lambert 1979; Strange-Vognsen 1991). Open reduction and internal fixation have traditionally been deemed to be essential to obtain optimal outcomes and to enable safe, early joint mobilization (Schatzker 1988).

Articular cartilage may be damaged by the initial joint impact (Borrelli et al. 1997; Mankin 1982)

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or due to degenerative conditions secondary to intra-articular fracture. Acute joint injury directly causes chondrocyte death or dysfunction that can progress over 48 h after the initial injury (Tochigi et al. 2011). The mechanisms whereby cell death induces joint degeneration and PTOA are unknown, but the release of oxygen radicals and/or pro-inflammatory mediators following injury is thought to play a role by progressively leading to chondrocyte damage and matrix degeneration (Goodwin et al. 2010; Green et al. 2006; Guilak et al. 2004; Martin and Buckwalter 2006). Moreover, the repair of articular cartilage damage associated with subchondral bone fractures mainly consists of fibrocartilage, which has inferior mechanical properties and less durability compared with native articular cartilage (Salter et al. 1980). Moreover, other related factors, such as meniscal injury, malalignment, or instability of the knee resulting from the trauma, may increase the stress on the articular surface and further increase the risk of degeneration (Davis and Moskowitz 1973; McDevitt et al. 1977).

An appropriate postoperative treatment is mandatory to prevent adhesions and restore early range of movement and more physiologic long-term knee function (Mitchell and Shepard 1980). Factors including immediate joint injury, articular incongruity, joint instability, malalignment, and poor postoperative management may contribute to the development of PTOA. The optimal clinical approach for the treatment of intra-articular fractures is to restore congruity, stability, and alignment in order to minimize the risks of PTOA onset. However, once PTOA has developed, treatment to address both anatomy and symptoms have been proposed for patient management. The aim of this chapter is to summarize the biologic and tissue engineering strategies currently available to help improve the treatment of joint conditions following articular injuries, in order to restore articular cartilage and decrease or slow down the progression of PTOA.

5.2 Articular Cartilage Surgical Treatment

The general indication to surgically address a contained focal articular cartilage defect is based on the presence of symptoms, which persist after at least 3–6 months of conservative management including physiotherapy, activity modification, and body-weight reduction (Cole et al. 2009; Gomoll et al. 2010). However, in case of large defects in very young patients, as well as in those affected by severe post-traumatic lesions, this indication can be widened. In fact, these lesions are likely to progress, with secondary degenerative changes throughout the whole joint (Madry et al. 2016). Young and otherwise healthy patients with post-traumatic articular cartilage defects usually have limited therapeutic options. In these cases, preoperative planning must first carefully consider all joint comorbidities that can frequently occur in association with intra-articular fractures. Subsequently, the most appropriate technique should be selected. For example, bone marrow stimulation, the most used cartilage treatment procedure for chondral lesions, is usually contraindicated both in osteochondral lesions and in cases of large or degenerative defects. In such cases, other procedures have a better indication for post-traumatic articular lesion management.

5.2.1 Reconstructive Procedures

Autologous osteochondral transplantation (OAT) is a reconstructive approach involving the surgical transfer of viable osteochondral plugs bringing intact hyaline cartilage into the damaged area, while taking advantage of direct bone-to-bone healing. These features are particularly important for the treatment of post-traumatic articular cartilage defects. Autologous osteochondral grafts can be harvested from a low weight bearing area of the same knee, and the procedure can be performed by arthroscopic or open surgery, depending on the site and size of the defect. Single massive plugs were shown to produce reliable results in long-term follow-up (Marcacci et al. 2007), but the same group observed limited clinical results due to a significant amount of anterior knee pain related to donor site morbidity (Filardo et al. 2014). A mosaicplasty technique using multiple smaller, cylindrical plugs was therefore proposed to address larger defects while reducing donor site morbidity. Overall, good long-term clinical follow-up results have been reported in the literature, including favorable results among athletes (Gudas et al. 2012; Hangody et al. 2010). However, some limitations were reported for large defects or for those requiring a large number of plugs (Andrade et al. 2016; Filardo et al. 2015b). The greater the number of grafts used, the greater the surgical difficulty to effectively restore normal joint surface curvature. This can create abnormal stress distribution, leading to fibrous tissue development within the spaces between the plugs. Donor site morbidity is a major drawback of the OAT techniques, which severely limits the use of these procedures to address large defects, like those resulting from intra-articular fractures (Andrade et al. 2016). Conversely, osteochondral allografting (OCA) allows the replacement of a damaged osteochondral unit with a viable tissue harvested from a donor, thus avoiding the issues related to donor site morbidity. Therefore, it represents a suitable option for the treatment of large knee defects. This approach was shown to provide a clinical improvement in a variety of knee articular surface conditions, ranging from the treatment of primary articular cartilage defects to large osteochondral defects, osteonecrosis, or as a salvage option in case of failed previous articular cartilage repair. It can also be used for complex biologic knee reconstructions in the PTOA setting (Sherman et al. 2014). Drexler et al. (2015) treated 27 symptomatic patients following lateral plateau fractures with OCA combined with distal femur osteotomy and reported good or excellent results in most cases, with 89% survivorship at 10-year follow-up. Ghazavi et al. (1997) used fresh small-fragment osteochondral allografts to reconstruct post-traumatic osteochondral defects in 123 patients with a mean age of 35 years, with 71% survivorship at 10 years and 66% at 20 years. Similarly, Beaver et al. (1992) treated 92 post-traumatic defects of the knee with OCA and observed a success rate of over 80% at 10 years after surgery. Whereas the outcomes reported for OCA are satisfactory and durable over time, and the procedure has shown promising findings even when applied in post-traumatic articular defects, the technique cannot be universally implemented due to strict legal regulations that exist in many countries, its relatively high costs, and also due to difficulties in obtaining and handling fresh grafts (Bugbee et al. 2016).

5.2.2 Tissue Engineering and Scaffold-Based Procedures

The limitations of the aforementioned procedures have promoted the development of ambitious regenerative options, aimed at maximizing the body's self-regenerative potential to heal injured articular cartilage with tissue that more closely resembles articular cartilage. Autologous chondrocyte implantation (ACI) is the first and most documented among these regenerative procedures for articular cartilage treatment. First-generation ACI involved the injection of a cell suspension under an autologous periosteal flap that had previously been sutured to the surrounding articular cartilage as coverage of the defect (Braun et al. 2008). Despite limited evidence produced about the application of ACI into post-traumatic articular cartilage defects, some authors highlighted promising results for the treatment of large articular cartilage defects with satisfactory clinical outcomes in long-term follow-up (Minas et al. 2014), suggesting its suitability to target large post-traumatic defects of the knee (Basad et al. 2010; Beris et al. 2012; Knutsen et al. 2004). However, despite good and durable clinical results offered by first-generation ACI, some drawbacks were mentioned. The need of an open, technically demanding surgery and the relatively high rate of hypertrophy of the periosteal graft (Niemeyer et al. 2015) promoted the development of new-generation techniques, where cultured chondrocytes were seeded into three-dimensional scaffolds (mainly type I/III collagen- or hyaluronan-based) to avoid handling the liquid suspension and to better enable bioengineered tissue implantation. Some of these procedures even allow an arthroscopic implantation (Kon et al. 2012). Furthermore, these chondral procedures could be combined with bone grafts to address deeper osteochondral defects, which frequently occur with intra-articular fractures (Filardo et al. 2012).

Matrix-assisted ACI (MACI) procedures were investigated for treatment of large knee osteochondral defects up to 12 cm^2, with positive results in long-term follow-up (Kon et al. 2012). Nevertheless, this kind of lesion often occurs in a degenerative joint environment which is a relative contraindication for MACI procedures, since it has been correlated to lower regeneration potential and, consequently, inferior clinical outcomes (Filardo et al. 2012, 2013c). In this light, the role of subchondral bone on the quality of the overlying articular cartilage has been acknowledged, and the subchondral bone layer is thought to be involved in the ongoing degenerative processes associated with most large post-traumatic osteochondral defect cases (Filardo et al. 2013a). These considerations, together with the need for two different surgeries (the first for chondrocytes harvest and subsequent culture expansion and the second for implantation), promoted research toward a one-step, cell-free osteochondral regenerative surgical procedure. This was made possible through the development of materials able to stimulate resident cells attachment, proliferation, and differentiation after being implanted directly into the defect with no cell augmentation (Kon et al. 2014b).

For this reason, treatment of the entire osteochondral unit was proposed to improve the results offered by chondral-only procedures. This represents a challenging issue, due to the need to restore two different tissues characterized by having completely different intrinsic healing capacities. Biphasic scaffolds have been developed to better reproduce the different biological and functional requirements of both subchondral bone and articular cartilage, eventually providing ordered and effective osteochondral tissue regeneration. Several osteochondral constructs were developed and investigated at preclinical level, but only a few have been approved for clinical use. Among these, MaioRegen™ (Fin-ceramica, Faenza, Italy) is more specifically targeted to address large post-traumatic or degenerative osteochondral defects.

The MaioRegen™ scaffold is the most widely documented cell-free osteochondral implant. It has a nanostructure which consists of three graded layers of collagen type I and hydroxyapatite and can be implanted through an arthrotomic approach (Fig. 5.1). After promising preliminary findings, many reports showed satisfactory outcomes for up to 5-year follow-up in heterogeneous populations. Among the various knee conditions investigated, a study specifically eval-

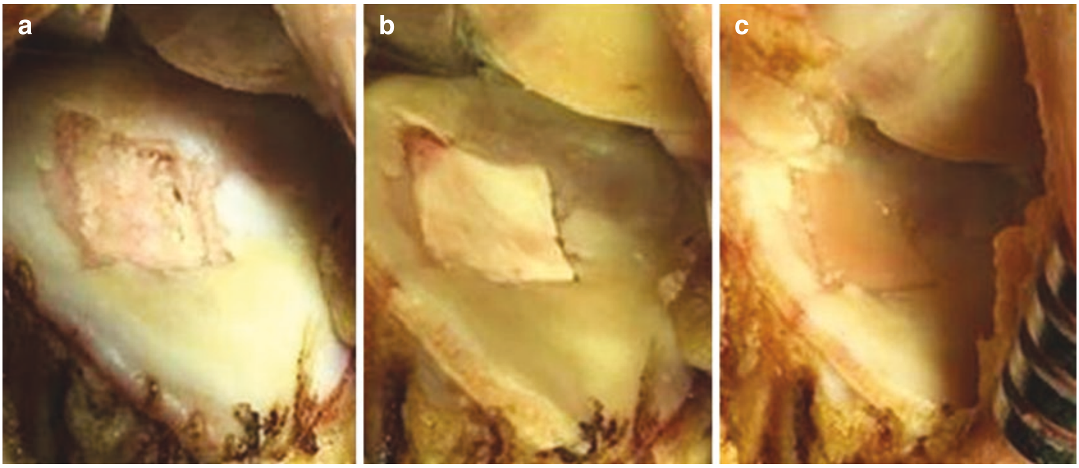

Fig. 5.1 Post-traumatic defect of the tibial plateau in a 45-year-old male, treated with the implantation of a biomimetic osteochondral scaffold. (**a**) Defect preparation involving the excision of the damaged osteochondral tissue. (**b**) Implantation of the osteochondral scaffold, sized and shaped according to the defect characteristics. (**c**) The scaffold is placed into the defect and covered with fibrin glue on the surface and at the interface with the surrounding tissues

Fig. 5.2 MRI at 10 years' follow-up after an osteochondral scaffold implantation in a 50-year-old woman for a severe post-traumatic symptomatic defect of the lateral tibial plateau. Despite the anatomical abnormalities and the degenerative changes of the treated compartment, the procedure provided lesion coverage and the patient is pain-free with no activity limitations

uated the results after implantation of the osteochondral scaffold to 11 patients affected by osteochondral defects of the tibial plateau (9 of them post-traumatic) (Kon et al. 2014c) (Fig. 5.2). The clinical scores showed a significant improvement at 2-year follow-up, with no major complications, confirming that this approach might be suitable to improve the outcomes of patients with post-traumatic articular cartilage defects at short-term follow-up. Further studies with longer follow-up will be able to highlight the durability of these results. Despite this limited evidence regarding the treatment of articular cartilage defects following intra-articular fractures, several studies confirmed the effectiveness of this procedure in cases of large articular defects, with promising clinical results at 24-month follow-up for lesions over 4 cm^2 (Berruto et al. 2014). Interestingly, lower activity level and older age were significantly correlated with worse clinical outcomes, suggesting that this regenerative approach is less effective in older patients with limited regenerative potential (Berruto et al. 2014). Similar age limitations, but still satisfactory overall results at 36-month follow-up, were reported in the setting of relatively young patients with early (Di Martino et al. 2015) or unicompartmental OA (Marcacci et al. 2013). These results confirm the possibility to address articular cartilage defects in an OA environment with the use of this osteochondral implant as a salvage procedure alternative to metal resurfacing for younger patients. This is particularly interesting since these types of defects commonly occur in patients affected by PTOA. Finally, the first report evaluating midterm results confirmed stable clinical outcome score improvement over time in 27 patients with mixed-type lesions (Kon et al. 2014a). Some issues were raised concerning the imaging appearance of the implant (CT or

MRI) (Christensen et al. 2016; Perdisa et al. 2017), but a general improvement of MRI parameters was observed over time (Kon et al. 2014a), although without any correlation to the clinical scores. Therefore, this approach represents a suitable option for the treatment of large post-traumatic osteochondral defects in a younger patient population, where limited options are available (Kon et al. 2014b). However, age-related limitations have been observed, and these should be considered in the treatment indication, which should be planned carefully taking into account the need to address any possible comorbidity. Future studies should focus on technological improvements with cell augmentation to ameliorate the regenerative potential and possibly favor healing of the more difficult cases, such as larger lesions in older patients and a post-traumatic degenerative environment. To this regard, promising findings have been recently documented applying a one-step surgery with multipotent stem cells through a bone marrow concentrate application for the treatment of large full-thickness chondral defects (Gobbi et al. 2014), with signs of regeneration of the articular surface in patients previously doomed to inferior clinical outcomes and otherwise considered to be arthroplasty candidates.

5.3 Nonsurgical Articular Cartilage Treatment

Patients with uncontained lesions, where a more complex degenerative environment has already developed following an intra-articular injury, such as in PTOA, or those with associated older age represent a theoretical contraindication for surgical treatment, which is better suited to restore focal articular defects. In fact, most surgical options are less effective in more degenerated joints and older patients (Filardo et al. 2016a). Thus, nonsurgical management is generally indicated in this group characterized by a low regenerative potential, with the aim of improving joint function and temporarily reducing symptoms in order to delay the need for metal resurfacing as long as possible. PTOA may be addressed by a wide range of nonsurgical approaches, from activity modifications to dietary supplements and pharmacological or physiotherapy. Moreover, novel biological procedures that involve the intra-articular injection of various substances may ameliorate the symptoms and even provide some disease-modifying effects.

5.3.1 Injections

Specific local treatments aimed at improving joint homoeostasis, or even counteracting tissue damage by inducing regenerative processes, may be successful in PTOA, especially when tissue loss and anatomical changes are still at mild stages. The vast majority of pharmacological research for OA has focused on preventing or delaying mid- to late-term joint degeneration (Hellio Le Graverand-Gastineau 2009; Pelletier and Martel-Pelletier 2007). Intra-articular injections of corticosteroids were first described in 1951, and they are still considered a cost-effective milestone among noninvasive OA treatments. The rationale for their use is the anti-inflammatory effect through a complex multiplicity of actions (Hollander 1951), including the prolonged concentration of corticosteroid in the synovial fluid that would achieve the maximum anti-inflammatory local effect while minimizing the risk of systemic effects (Hollander 1951). Recent studies showed how a single injection of extended-release corticosteroid formulation might diminish the early inflammatory response and, eventually, delay post-traumatic alterations leading to early OA (Bodick et al. 2015; Heard et al. 2015). This evidence suggests a possible new paradigm for intra-articular steroid use, by "reversing" their traditional chondrotoxic reputation. However, further studies are needed to confirm the real benefit of a single intra-articular corticosteroid injection in a post-traumatic or post-surgical setting, in reducing the acute phase of inflammation, the production of metalloproteinase, and inflammatory mediators and, as a consequence, in reversing the degenerative vicious cycle initiated by joint damage (Huebner et al. 2014).

Intra-articular hyaluronic acid (HA) derivative injections have been proposed as interventions to delay or prevent PTOA progression (Huang et al. 2010; Hurtig et al. 2009; van Brakel and Eygendaal 2006). Hyaluronic acid is believed to act by attenuating the catabolic activities of fibroblast-like synoviocytes, which release pro-inflammatory cytokines and enzymes. In vitro study of cells derived from synovium of patients with tibial plateau fractures have shown that HA has both anti-inflammatory and chondro-protective properties (Huang et al. 2010). However, a clinical trial showed that intra-articular injections of HA were not effective in a group of patients with PTOA of the elbow (van Brakel and Eygendaal 2006).

5.3.2 New Injective Biological Approaches

Platelet-rich plasma (PRP) is a blood derivative that has recently gained high interest for its supposed anabolic and anti-inflammatory properties due to its abundance of growth factors (GFs) and bioactive molecules stored in platelet α-granules, which take part in the regulatory pathways of articular cartilage healing (Filardo et al. 2015c). Preclinical evidence has showed positive joint homeostasis effects, thus supporting the rationale to apply this treatment in joint degeneration cases. Randomized controlled trials (RCT) available for knee OA have provided an overall support to PRP injections, with an early beneficial effect compared with placebo and slightly superior results than those obtained with viscosupplementation (Gormeli et al. 2017). In addition, better results were achieved in younger patients and those affected by early OA (Filardo et al. 2015c). However, the superiority of PRP over HA has been recently been questioned in a double-blind RCT on a large cohort of patients, which documented a similar response to treatment at 12-month follow-up, even in patients affected by earlier stages of knee degeneration (Filardo et al. 2015a). Despite these controversies, PRP represents a promising option for the treatment of degenerative conditions, but the best formulation and application modalities are still under investigation in order to optimize the treatment of joints affected by OA.

Finally, mesenchymal stem cells have recently emerged as an injective treatment option to target OA. More than their structural contribution to tissue repair, the most recent evidence supports their immunomodulatory and anti-inflammatory action, through direct cell-cell interaction or secretion of various factors (Filardo et al. 2013b, 2016b). Safety and positive clinical results have been reported for this approach to treat knee degenerative lesions, but further studies are still needed to clearly prove their effectiveness in PTOA.

5.4 Conclusion

The treatment of post-traumatic articular cartilage or osteochondral defects is a challenge for the surgeon, with several factors to be considered. A thorough consideration of all comorbidities should be performed when deciding upon the best intra-articular fracture management method, since they put patients at high risk of further joint degeneration and PTOA. For the specific issue of post-traumatic articular cartilage injury, surgical options are indicated in cases of critical focal defects. As conventional procedures showed several limitations, new regenerative options have increased the possibilities of intervention and showed promising results. However, further studies are necessary to better delineate their true efficacy. Finally, local injective therapies can be applied to post-traumatic joint injuries either to prevent further damage in the early phases or to treat late symptoms due to the altered articular environment in PTOA. Despite their early promise proven by preclinical testing and promising preliminary clinical evidence, the extent of their regenerative effect remains to be determined and research efforts should aim at clarifying indications and true potential for treating joints affected by intra-articular fractures.

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6

Rehabilitation Principles Following Minimally Invasive Fracture Fixation

John Nyland and Defne Kaya

6.1 Introduction

Healthy joints serve as the transmission to function. Movement and healthy, regular loading are paramount to joint preservation. All too often, the result of poor intra-articular fracture management is premature osteoarthritis onset. Osteoarthritis affects millions of people worldwide, is associated with joint stiffness and pain, and often causes significant disability and loss of productivity. Poor intra-articular fracture management leads to post-trauma osteoarthritis that may accelerate the joint "wear and tear" that normally occurs during the course of activities of daily living. Progress in the use of chondroprotective nutritional or pharmaceutical agents may help to slow or prevent the future development of post-traumatic osteoarthritis (Bansal et al. 2014; Caborn et al. 2004; Chubinskaya et al. 2015). The purpose of this chapter is to identify considerations and concerns that may influence the rehabilitation of patients who have sustained intra-articular fractures.

6.2 Postsurgical Malalignment, Segment Length, or Joint Surface Inclination Changes

Whether an intra-articular fracture has been managed through closed reduction and fracture site stabilization through casting or through open reduction and internal fixation with pins, screws, plates, or rods, with or without osteotomy, the rehabilitation physiotherapist must be concerned about how the three-dimensional healing fracture site orientation may modify joint loading during weight-bearing and other functional activities (Auer et al. 2016; Eismann et al. 2015; Lewek et al. 2004a, b; Vandenberghe et al. 1990). Shorter femoral or tibial length post surgery would tend to increase involved lower extremity joint reaction forces at the shorter lower extremity. Increased proximal tibial plateau anterior or posterior inclination would tend to increase injury risk to the posterior cruciate or anterior cruciate ligament, respectively (Schillhammer et al. 2016; Shelburne et al. 2011). Residual transverse plane femoral internal rotation and/or tibial external rotation may promote lateral patellar translation, while medial translation may occur with femoral external rotation and/or tibial internal rotation. When joint contact forces are altered, specific articular cartilage regions will experience either increased or decreased loading forces. Articular cartilage loading force or

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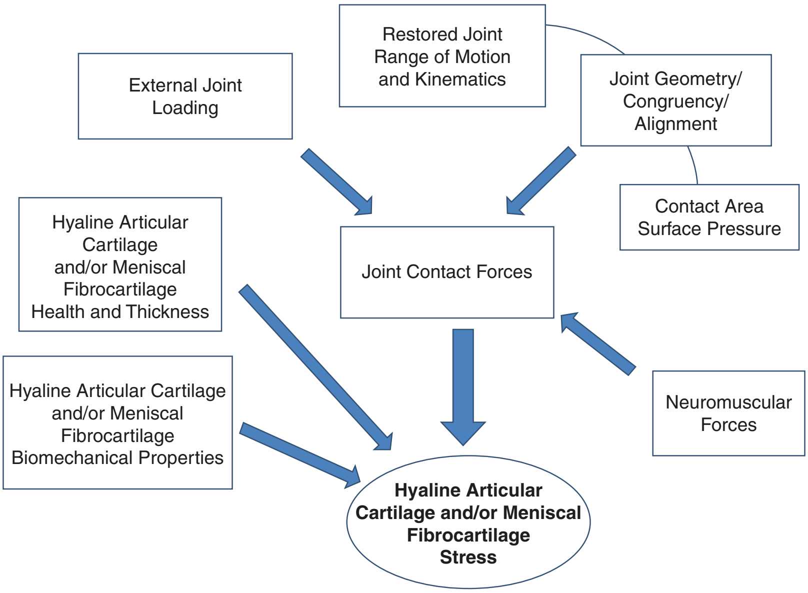


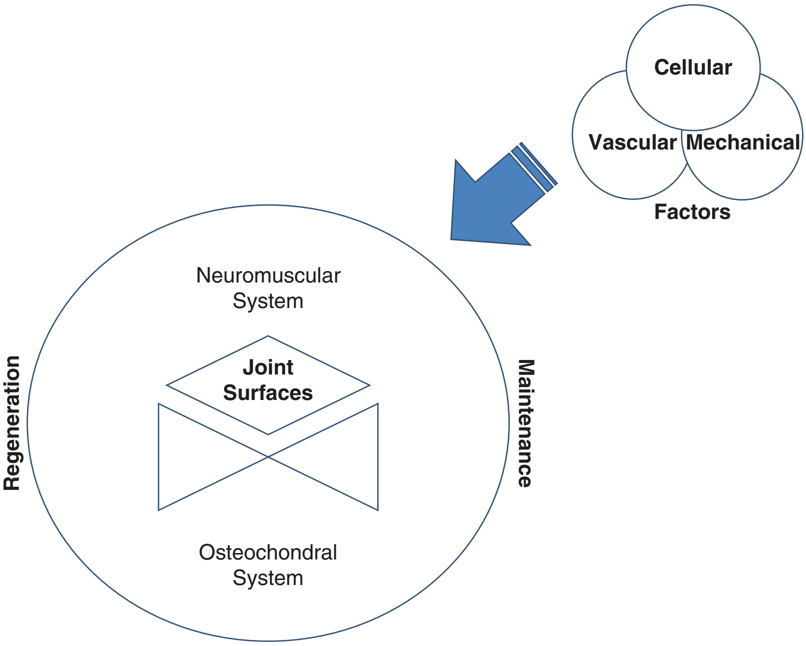
Fig. 6.1 A variety of factors may contribute to articular cartilage stress

pressure changes may also result from the over-constraint associated with joint range of motion restrictions or overzealous capsuloligamentous imbrication, ligament repair or reconstruction, or the hyper-laxity associated with increased residual joint translational forces following unaddressed or poorly managed joint capsuloligamentous injuries (Fig. 6.1). Auer et al. (2016) reported that distal radius fracture malreductions were more prevalent among obese children treated with closed reduction and casting. These findings support the need for close follow-up and early consideration of additional treatment among this population to reduce malreduction risk, particularly if intra-articular components exist. The physiotherapist must be cognizant of these potential factors, including whether or not functional bracing, including joint compartment pressure off-loading braces, is needed to preserve joint health (Mueller and Maluf 2002).

6.3 Healing Potential

Post surgery, restricted weight-bearing (Haller et al. 2013), joint range of motion, and impact loading constraints generally exist for variable time periods (LaStayo et al. 2003a). The physiotherapist must dialogue with the orthopedic surgeon in terms of how aggressive they can be in attempting to normalize joint range of motion. Restored joint mobility is foundational to recovery following any intra-articular fracture (Ackerson et al. 2015; Farsetti et al. 2009; Onderko and Rehman 2013; Salter 1994; Salter et al. 1980). Physiotherapists should obtain a firm understanding of the reasons for imposed restrictions and the rationale behind sequentially removing these restrictions. In addition to known physiological joint healing factors (Fig. 6.2) (Duda et al. 2008), joint use restriction may also be influenced by concerns related to patient

Fig. 6.2 Cellular, mechanical, and vascular factors influence the regeneration and maintenance of the neuromuscular and osteochondral systems



compliance, lifestyle, past medical history, general health, the presence of any comorbidities, gender, general bone/joint health, neuromuscular functional status, and fixation/graft use concerns (Bianchi et al. 2009; Fitzgerald 2005).

6.4 Articular Surface Congruency

From the perspective of joint function preservation, one of the most important factors associated with intra-articular fracture management is re-establishing normal joint articular surface congruency (Colegate-Stone et al. 2015; Eismann et al. 2015; Lachiewicz and Funcik 1990; Liodaki et al. 2015; Lubowitz et al. 2004, 2005; Margles 1988; Thomas et al. 2011). To help achieve this, some have advocated using arthroscopic-assisted surgical techniques to better evaluate the joint surface fracture site, verify fracture reduction effectiveness, and help improve patient outcomes (Turhan et al. 2013). With proper management, even surgery in the treatment of complex, glenoid fractures, with or without scapular neck or body involvement, can be associated with good functional outcomes and with a low rate (Anavian et al. 2012). At the knee, healthy menisci are essential and much should be done to preserve, repair, or replace injured meniscal tissue whenever possible to protect femoral condyle articular cartilage, thereby preventing or at least delaying the knee osteoarthritis progression (Nyland et al. 2018) (Fig. 6.3).

Fig. 6.3 Healthy menisci are essential to tibiofemoral compartment articular cartilage preservation and osteoarthritis prevention. Surgeons should attempt to preserve, repair, or replace this vital tissue whenever possible

6.5 Potential Stress Shielding or Stress Riser from Fixation Hardware

After restoring intra-articular fracture site joint surface congruity, the surgeon may use metal, permanent polymer, or bioresorbable polymer material components such as pins, screws, plates, or rods to ensure that the fracture site stays reduced. While each of these components may provide the needed fixation, it is important for the physiotherapist to understand how the same devices that protect the intra-articular fracture site from the potentially destabilizing loads that might lead to reduction failure may also ultimately stress shield fracture region healing (Driscoll and Blyum 2011). This may result in fracture site bone strength that never approaches pre-injury levels. Another concern is the possibility of fracture fixation materials creating a stress riser effect either directly at the fracture site or at an adjacent joint region. Fixation materials may serve to overprotect the fracture site resulting in less than optimal bone healing. Fixation devices may also concentrate peak loading forces at adjacent joints promoting potentially injurious loading at these sites. Physiotherapists need to consider each of these possibilities as they guide the patient through the rehabilitation process and eventual release to unrestricted vocational or sports activities.

6.6 Patient Expectations "Realistic or Not"

Depending upon the location, severity, reduction effectiveness, fixation integrity, and healing capacity of the intra-articular fracture, the patient may need to modify their expectations regarding what activities they can safely return to. This may be particularly true when intra-articular fractures involve weight-bearing joints. Repetitious and/or high-magnitude joint impact loads may compromise repair site integrity, particularly if residual articular cartilage damage exists. In these situations, the physiotherapist must educate and guide the patient through the decision-making process regarding quality-of-life values and behavioral change recommendations to better preserve joint health. Establishing realistic goals in terms of the rehabilitation progression and return to unrestricted function is essential. Even when the patient is deemed ready for release to vocational or sports participation, it may be a good idea to encourage them to better balance the joint loading requirements of their preferred activity with less impact producing conditioning activities. Essentially, they should be encouraged to safe primary weight-bearing joint loading for quality-of-life-enhancing activities, not for repetitive training in preparation for those activities. In conjunction with this, patients who possess a well-tuned dynamic neuromuscular joint control system and skill set for a particular vocational or sports activity are more likely to safely return, particularly if they adhere to necessary pre-activity conditioning and joint load-sparing training activities.

6.7 Optimizing Full Kinematic/Kinetic Chain Function

In function the brain does not orchestrate the isolated joint- and muscle group-specific focus so commonly employed in therapeutic exercise regimens. Rather, it attempts to optimize neuromuscular activation and existing joint mobility capabilities to successfully perform movement tasks. Some level of either joint mobility or neuromuscular functional impairment may be permanent following intra-articular joint fracture healing. Therefore it is vital that the physiotherapist help the patient optimize function at joints and muscle groups adjacent to the site of intra-articular fracture, including the trunk or "core" whenever possible (Fig. 6.4). If something is partially taken away, such as fracture region joint mobility or neuromuscular function, something else should be given back. In other words, by improving adjacent joint and muscle group function, the therapeutic exercise program may be able to facilitate effective functional compensations that enhance performance despite fracture site impairments. Although the physiotherapist must justifiably need to focus

Fig. 6.4 Integration of non-impaired upper and lower extremity function through the trunk is important to achieving full patient recovery

Fig. 6.5 Restoring normal accessory joint motion at the involved joint and adjacent joints is essential to achieving the foundational mobility needed to improve strength, power, or endurance

much of their attention on the fracture site region, opportunities and responsibilities exist for evaluating and, if present, correcting impairments of adjacent and distal region musculotendinous extensibility, joint flexibility, and neuromuscular strength (Nelson et al. 1994). The lower extremities and spinal column may be particularly prone to injurious joint loading forces when impact loading vectors are transmitted through poorly aligned subtalar and midtarsal joints. This may create knee joint compartment-specific stress risers. Careful evaluation of the foot and ankle region should be performed to confirm complete non-impaired composite and segmental joint mobility (Fig. 6.5), intrinsic and extrinsic lower extremity neuromuscular strength, and near-neutral subtalar and midtarsal joint alignment. Consideration should also be given to how orthotic use and footwear interact to provide adequate joint postural control without over- or under-constraining functional foot and ankle joint mobility.

6.8 Patient/Client Understanding, the Importance of Therapeutic Lessons

The patient's level of understanding about the potential implications of their injury, its surgical or non-surgical management, rehabilitation course, and likelihood for safely returning to unrestricted activities is important. Likewise, it is important for the patient to perceive sincere, holistic dialogue with both the treating orthopedic surgeon and the physiotherapist. Through this dialogue, any notions regarding real or perceived potential barriers to a successful outcome can be mitigated. Likewise, the patient and their family can be informed about available treatment resources including items such as chondral-protective nutraceuticals and diets, the importance of controlling bodyweight, aquatic conditioning resources, and alternative care program such as Tai Chi (Wolf et al. 1997) or Yoga (Jakhotia et al. 2015) to be used as either supplements to the therapeutic exercise program or as primary post-rehabilitation training modes. It is also essential that the patient possesses a sound understanding of the rehabilitation timetable, short-term and long-term recovery goals, the importance of restriction compliance, the likely need to modify the rehabilitation progression when joint region irritation occurs, and the importance of trust and cooperation throughout the rehabilitation program. Since the patient and/or their family are likely to arrive with information obtained from the internet and other media sources, it is also important that the rehabilitation team guide them to the most reputable sources of information.

6.9 Optimizing Metabolic Energy System Function

Patients who sustain intra-articular joint fractures have highly variable health habits and fitness levels. Even the most healthy and physically fit individual, however, becomes less fit over the timeframe from the index injury, surgery and their associated healing time period requirements, rehabilitation, and activity-specific conditioning or work-hardening needs. Because of this, the patient's general metabolic system conditioning level may be sufficiently compromised to serve as a barrier to improving a wide variety of physical and social function goals and to ensuring a successful long-term treatment outcome (Nyland et al. 2005, 2016). This important, and often neglected, recovery component may pose a challenge not only with middle-aged and older subjects but also with young athletic patients who have not experienced the unique, sudden stressors associated with intense anaerobic and aerobic exercise and vocational or sports challenges for quite some time. When long-term uncorrected metabolic function exists, other improvements in strength, range of motion, and self-efficacy are likely to diminish when the metabolic energy system falters. When patients are released to complete unrestricted activities prior to re-establishing sufficient metabolic energy system integrity, they are more likely to employ faulty biomechanics during functional task performance (Powers 2003), thereby increasing joint loads to potentially injurious levels. When patients attempt movement tasks when fatigued or poorly conditioned, they are more likely to arrive late to the scene of the task necessitating greater reliance on maladaptive ergonomic compensations such as placing greater dependence on excessive reaching and forward or lateral leaning. When this faulty postural alignment occurs, the likelihood for joint reinjury increases as does injury to adjacent trunk and extremity joint regions.

6.10 Repetitive Microtraumatic, Acute Isolated, or Polytraumatic Intra-articular Fractures

Many intra-articular fractures occur from an isolated, traumatic event with minimal need to consider historical events from the patients' joint loading past. When an intra-articular fracture is associated with repetitive microtrauma at the joint or region of surgical interest, the surgeon and rehabilitation clinician need to obtain more information regarding the pathomechanics associated with the microtrauma. Recreational athletes may have a psychobehavioral dependence on activities such as distance running that warrants early postsurgical intervention to ensure that the healing tissues are given sufficient opportunity to remodel to physiologic loads. Likewise, patients who have physically demanding jobs such as manual laborers, those who climb ladders, or those who repetitively need to apply strong grip strength may need to agree to activity modifications depending on the status of the healing fracture. Lastly, when in conjunction with other more immediate life-threatening injuries, peripheral joint intra-articular fractures may not be given adequate attention (Balthrop et al. 2009). When this occurs the joint may heal with an incongruous, mal-aligned surface or with an unstable fracture site. These characteristics are likely to result in greater joint region pain, earlier osteoarthritis onset, and a poorer long-term patient outcome.

6.11 Pain

Pain is an individual human experience that is entirely subjective and can only be truly appreciated by the person who experiences the pain. Controlling acute pain post trauma or surgery is an essential element of early postoperative care following intra-articular fracture surgery (Macintyre et al. 2006). Physiotherapists may use a variety of therapeutic modalities either for pain control or bony healing with varying success in addition to individually prescribed therapeutic exercise programs. Patients with chronic pain however may possess significant associated psychobehavioral correlates that constitute a serious, distinct pathology of its own (Siddall and Cousins 2004). Chronic pain may also exist without a clear reason. While chronic pain associated with severe osteoarthritis may be effectively managed with therapeutic modalities, other types such as neuropathic pain or migraine-related pain may be more difficult to diagnose and treat. Chronic pain may be associated with neuroplastic changes in the peripheral and central nervous system. Poorly managed chronic pain can adversely influence patient quality of life. Most patients with chronic pain experience alterations in daily activities including sleep, sex, work, exercise, and routine self-care. This may create a negative effect on social interactions and lifestyle (Macintyre et al. 2006; Siddall and Cousins 2004).

Although the greatest incidence of chronic pain occurs between approximately 50–60 years of age, it may also occur in children and adolescents. Untreated chronic pain in children is likely to manifest in cessation of sporting or other activities once found to be important to their quality of life. This may result in early onset social isolation and depression that may foster adults who do not achieve their potential (Siddall and Cousins 2004). Early identification and intervention with patients who might be experiencing chronic pain symptoms is very important as a component of comprehensive intra-articular fracture management. In addition to behavior modifying interventions such as contracting, therapeutic exercises focused on the aerobic energy system and on self-efficacy enhancement during functional task performance may be especially effective. The physiotherapist needs to teach each patient to self-assess the fracture region to establish baseline and altered pain perceptions.

Whenever feasible, primary joint preservation should be the preferred surgical treatment pathway (Nyland et al. 2011). In contrast to total or partial joint arthroplasty procedures, with joint preservation surgery comes the likelihood that some joint-related pain may persist. This trade-off between preserving ones’ own tissue and their replacement with synthetic materials may be less than complete pain relief; however a likely greater list of physical activity options remains feasible since issues associated with prosthesis loosening, breakage, slippage, failure, or particulate debris accumulation do not exist.

6.12 Gender, Genetics, Lifestyle, and Age

Women may be more prone to developing osteoarthritis than men and are more likely affected by osteoporotic changes, joint laxity, and neuromuscular responsiveness or musculoskeletal stiffness fluctuations (Granata et al. 2002a, b; Quatman et al. 2006; Wojtys et al. 2003). Genetic predisposition, in terms of both primary osteochondral health and joint alignment, may also contribute greatly to the likelihood for preserving long-term joint preservation. In discussing patient recovery after having sustained an intra-articular fracture, the influence of lifestyle on the joint and function preservation prognosis cannot be discounted. Behaviors such as poor nutrition, smoking, excessive alcohol intake, and obesity may have a direct negative effect on intra-articular fracture healing or may have indirect effects through the promulgation of comorbidities such as type II diabetes mellitus and musculoskeletal, neuromuscular, cardiovascular, or pulmonary system diseases, in addition to osteoarthritis. The influence of lifestyle choices on physiological age may likewise negatively influence patient outcomes following intra-articular fractures. This may be especially true when these choices are combined with psychobehavior extremes such as repetitive or high-magnitude overuse or joint loading underuse.

6.13 Therapeutic Exercise to Improve Function and Cognitive Appraisal: Psychobehaviors

Cryotherapy such as ice massage or packs, cold water whirlpool baths, or combination cold compression devices may be used early post surgery to decrease acute pain, tissue edema, and joint effusion. Thermo-therapeutic modalities such as moist heat packs, ultrasound, or warm whirlpool baths may be used during the subacute recovery period to increase the circulatory response and tissue healing (Ebrahim et al. 2014). Electrical muscle stimulation or biofeedback may assist the patient in learning how to volitionally activate particular muscle groups that function through the injured joint (Lewek et al. 2004b). During both the acute and subacute periods, whenever possible, the physiotherapist should encourage the patient to actively move the involved joint through the prescribed range of motion. Combining modality use with active mobility activities can greatly increase the likelihood of long-term joint range of motion goal achievement. A variety of innovative therapeutic modalities such as laser light stimulation, instrument-assisted soft tissue mobilization, dry needling, and kinesiotaping may also be of use over the rehabilitation process; however the evidence basis supporting these applications is limited. Passive joint mobilization (non-thrust variety) may also be useful when active mobility is restricted. However, the physiotherapist must be extremely cognizant of fracture site healing status and residual joint congruency levels before applying grade I–IV oscillations. The end goal of any use of supplemental table, whirlpool, or aquatic-based plan applications is to help the patient advance to greater movement independence (Maly et al. 2005). The purpose of functional therapeutic exercises is to simulate the weight-bearing and non-weight-bearing components of specific daily activities in a manner that replicates three-dimensional lower extremity function within joint ranges and velocities that facilitate the desired physiological results (improved neuromuscular responsiveness and connective tissue integrity) (Nyland et al. 2005). Regardless of which peripheral joint has been injured, the most important factor other than fracture site healing is the restoration of normal, pain-free active joint range of motion. Without re-establishing joint range of motion, the full restoration of normal strength and functionality is unlikely. Both upper and lower extremity joints can benefit from weight-bearing (closed kinetic chain) and non-weight-bearing (open kinetic chain) therapeutic exercise movement tasks. However, from a functionality standpoint, most therapeutic exercise programs designed for the upper extremities focus on open kinetic chain reaching- and grasping-type tasks, while most designed for the lower extremities focus on closed kinetic chain, multidirectional movements (Fig. 6.6). In addition to obtaining a sound understanding of intra-articular fracture site healing, joint surface congruity, and range of motion restrictions, physiotherapists need to pay particular attention to the potential influence of either residual capsuloligamentous joint laxity from the index injury and/or surgical intervention, or tissue over-constraint related to prolonged immobilization, or the surgical intervention. In cases of residual capsuloligamentous joint laxity, the physiotherapist needs to

Fig. 6.6 Multidirectional movement proficiency is an important therapeutic exercise program component for many patients who desire to return successfully to intense athletic activities

focus on a therapeutic exercise plan that enhances dynamic joint stability. Associated with this may be the need to consider long-term functional brace use. In cases of over-constraint, the physiotherapist needs to be certain that they intervene as needed both with graded joint mobilizations and with non-weight-bearing therapeutic exercise tasks to capture as much pain-free active joint mobility as possible. Aquatic therapy may be of use anywhere along the rehabilitation care continuum postsurgical wound healing. Locomotion, multidirectional movements, and single-leg balance tasks performed while progressing from chest- to waist-deep water may be particularly useful to implement progressive weight-bearing post-lower extremity intra-articular fractures. The human body submerged in freshwater to waist level will experience only 40–50% of its weight on land. Standing in chest-deep water reduces weight-bearing to 25–30% of body weight and 10% when immersed to the base of the neck (Fig. 6.7) (Jamison and Ogden 1994). This results in low impact across the spine and other weight-bearing joint surfaces and is the primary basis for the safety and ease of aquatic exercise. While wearing a flotation vest, the deep end of a pool or a separate diving pool can also serve as an ideal environment for patients to regain full upper and lower extremity movement mobility. A variety of upper or lower extremity joint movement tasks can be prescribed as needed based on existing impairments. Composite upper extremity movement patterns may include slow speed “swim” (composite upper extremity over-to-under directed movements) or “rip” (composite upper extremity under-to-over directed movements), while lower extremity movement patterns focus primarily on “bicycling” movements and three-dimensional hip movements (Dwyer et al. 2010) in conjunction with knee flexion-extension and ankle dorsiflexion-plantar flexion. These movements may simulate diagonal 1 (D1) or diagonal 2 (D2) proprioceptive neuromuscular facilitation patterns as performed in the clinic under physiotherapist guidance (Fig. 6.8), using water resistance alone during active movements, or with enhanced resistance using exercise devices at the hands or feet (Weng et al. 2009). Knee or ankle mobility impairments often respond suc-

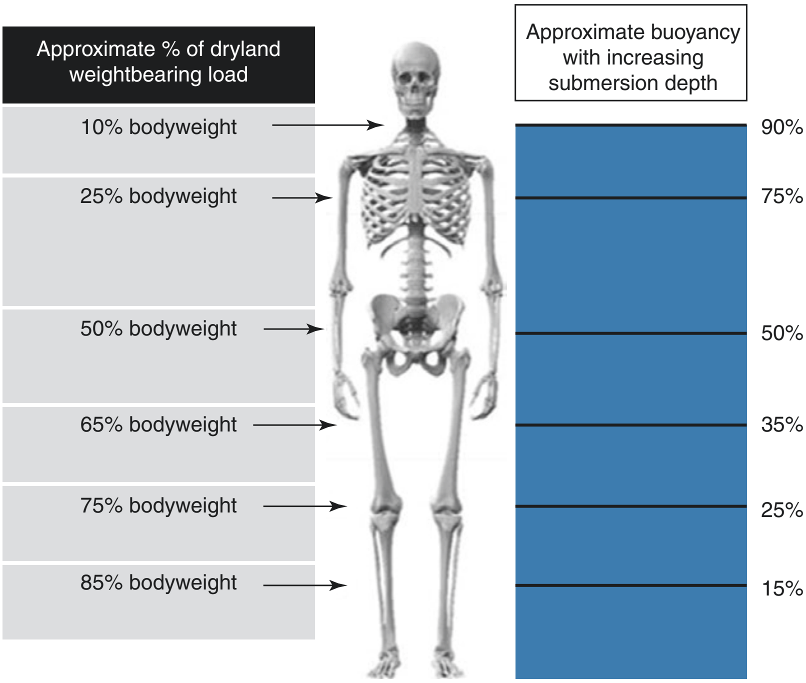


Fig. 6.7 The reduced weight-bearing associated with human body buoyancy in water is foundational to aquatic therapy effectiveness

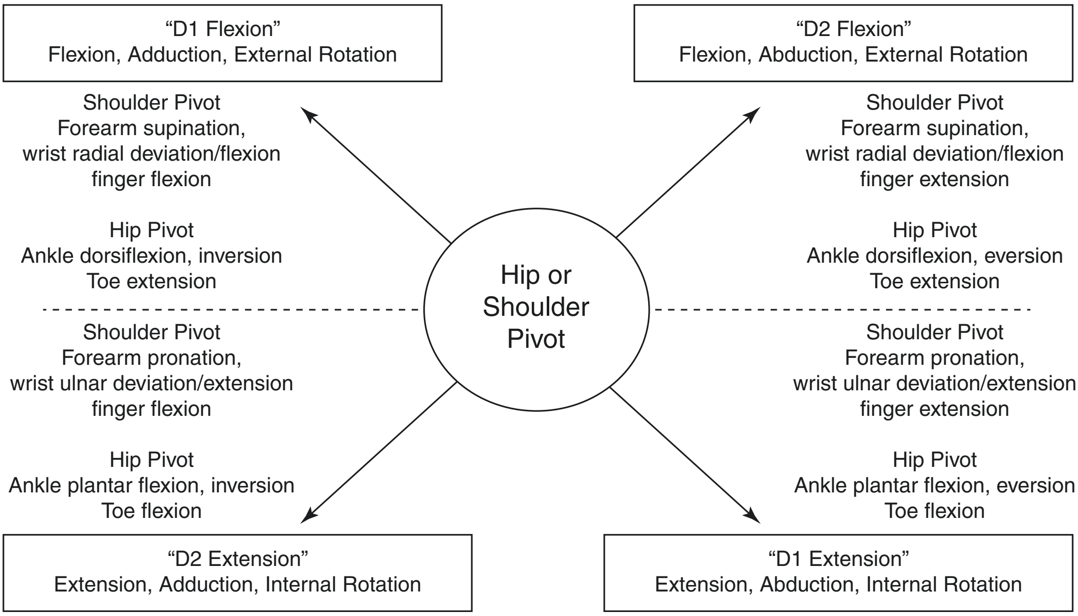


Fig. 6.8 Diagonal upper and lower extremity movement patterns help improve joint range of motion and coordinated function

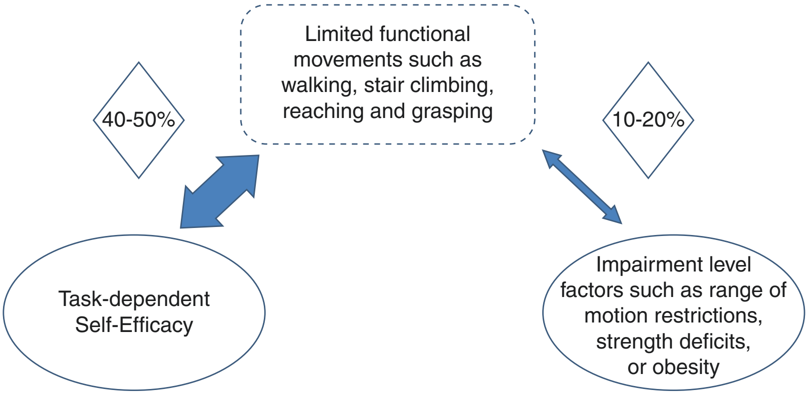


Fig. 6.9 The self-efficacy that a patient perceives related to a specific movement task may ultimately be a stronger functional capability determinant than impairment level measures of strength, joint range of motion or excessive bodyweight

cessfully to composite movements performed in conjunction with the hip (Dolak et al. 2011) moving from relative hip flexion-abduction-external rotation to hip extension-adduction-internal rotation. Impaired shoulder, elbow or wrist mobility may be restored as the patient performs progressive "rip" movements while floating in prone or progressive swim-type movements while floating in supine. Although wrist and hand mobility restrictions may benefit from these movements also, focused graded joint mobilizations may be needed during regular clinic treatment sessions to achieve joint range of motion goals (LaStayo et al. 2003a).

During movement training, the physiotherapist evaluates the patient for postural predispositions such as evidence of dynamic hip adduction-internal rotation and knee valgus loading, excessive thoracolumbar kyphosis or lordosis, and excessive forward or lateral trunk and pelvic tilt alignment during single-leg jump landings (Fitzgerald et al. 2001; Hewett et al. 1996; Joseph et al. 2008). These pathomechanical movement patterns may promote lower extremity or low back injury. In addition to actual movement task performance, the physiotherapist should ascertain how the patient perceives (cognitive appraisal) their current functional state and their psychobehavioral attributes (self-efficacy, fear avoidance, health locus of control) when confronted with progressively more difficult challenges (Brand et al. 2013). Ultimately, the patient's psychobehavioral status may be a stronger long-term outcome determinant than physical function capability (Maly et al. 2005) (Fig. 6.9). This may be particularly important when attempting to return to athletic activities at the same frequency and intensity level as before the injury.

6.14 Therapeutic Exercise and Patient Education

The therapeutic exercise environment is an ideal place for the physiotherapist to provide important health-related information to the patient as part of an instructional dialogue that trains proper movement education, self-efficacy (Brand et al. 2013), and metabolic energy system enhancement (Fig. 6.10). As the patient initiates early postsurgical joint loading, it is essential that they learn how to cognitively appraise the magnitude, frequency, and location of task-related joint pain in a more objective manner. Associated with any therapeutic exercise program that attempts to progressively increase the total volume, intensity, and frequency is the likelihood that joint region pain, tenderness, or effusion may occasionally increase. This is in contrast to the desired muscular discomfort associated with an intense, productive training session. When little or no muscular discomfort in the joint region of interest exists, with increasing joint region pain, tenderness, and swelling, immediate program modification is needed to minimize the inflammatory response. Any time increasing patient expectations are juxtaposed with increasing pain and decreasing function, the physiotherapist should make note and act accordingly to redirect the patient's recovery trajectory, never discounting the benefits associated with active rest and a few days without joint impact loading. When evaluating functional movements, the physiotherapist should verify the presence of balanced and bilaterally symmetrical contributions from the hips, knees, and ankle-foot of each lower extremity. They should also watch for any compensatory movements that suggest favoring of the injured region. Prior to progressing the patient to rehabilitation or conditioning challenges beyond elemental impairment-level therapeutic exercises, it is important to restore as close to normal joint range of motion and musculotendinous extensibility as possible. Early therapeutic

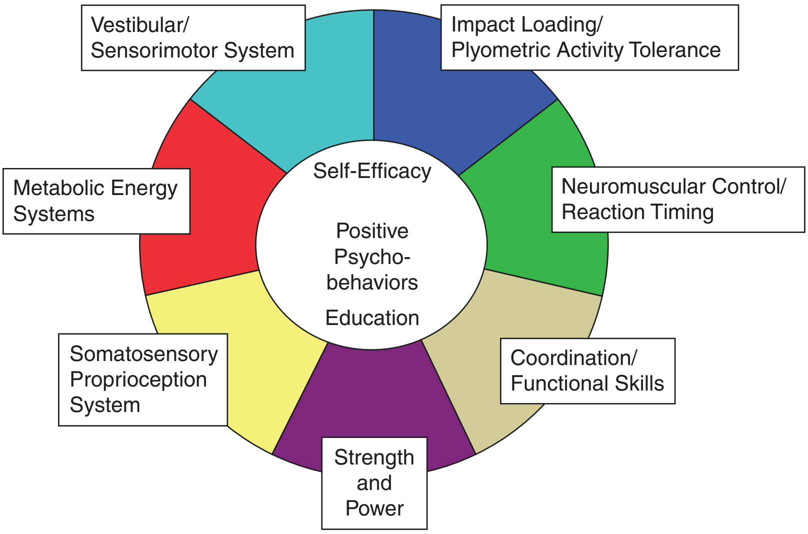


Fig. 6.10 Rehabilitation planning focuses on restoring many facets of functional capability; however improved task-dependent self-efficacy, positive psychobehaviors such as weight loss or smoking cessation, and patient education are essential to achieving successful outcomes and preventing reinjury

Fig. 6.11 Single-leg stance sensorimotor training while throwing and catching a tennis ball (multitasking) can enhance dynamic lower extremity joint stability in conjunction with upper extremity and trunk or "core" muscle use

exercises that focus on improving dynamic joint stability from proximal to distal should be added upon a foundation of normalized joint mobility (Fig. 6.11) (Chaudhari et al. 2005). In a progressive fashion, sudden perturbations can be applied distal or proximal to the involved joint to facilitate the instantaneous neuromuscular co-activation reactions that enhance dynamic joint stability. Maintaining closed eyes during volitional or unexpected perturbations can further stimulate protection neuromuscular responses without having to increase load magnitude or movement velocity. This may be particularly important when intra-articular fracture healing is incomplete or if articular cartilage in the fracture region needs additional time to remodel prior to being able to withstand greater impact loads.

Progressively more intense movements performed outside the primary, sagittal flexion-extension movement plane may be particularly important following intra-articular knee or ankle fractures. The substitution of more frontal plane abduction-adduction with greater hip joint contributions to integrated hip-knee-ankle movements may help alleviate knee and ankle joint discomfort during intra-articular fracture recovery. As tolerated, the movement path can be redirected diagonally back from a more frontal to a more sagittal movement path as the patient's pain level tolerates. Ideally, functional movements should blend balance, coordination, and postural control tasks that are relevant to the sport, occupation, and impairment or functional limitation alleviating the needs of the injured joint. During movements such as these, it is important that the physiotherapist be vigilant to ensure that movement quality is high with a symmetrical balance between side-to-side hip-knee-ankle and shoulder-elbow-wrist movement contributions. For example, if single-leg lateral step-up exercises are performed using increased trunk or hip flexion, the loading vector tends to move anterior to the knee joint shifting the composite lower extremity toward a greater contribution from the hip extensors than from the knee extensors. This may be particularly problematic if the knee is the region of rehabilitation concern as exercises performed like this minimize desired knee extensor recovery. Similarly, if shoulder or elbow mobility is restricted during an overhead reaching and grasping or catching task, the patient will be more likely to evoke maladaptive compensatory wrist or trunk movement substitutions. The therapeutic exercise environment also provides an excellent opportunity for patient education about appropriate nutrition and hydration, metabolic energy system training rest-work interval requirements, and self-evaluation. Basic instruction in the relationship between faulty movement postures/techniques and increased reinjury and/or joint pain risk should be provided. Tasks should be selected in a progression from low to higher intensity, longer to shorter recovery periods, relatively simple to more complex, and from relatively planned to more chaotic (Nyland 2012; Nyland et al. 2016).

During functional therapeutic exercise movements, patients need to experience movement path variations as part of the recovery process. All too often following intra-articular joint injury and surgery, movement patterns become constrained contributing to concentrated, higher impact joint reaction forces (Nyland 2012). This sets the stage for accelerated joint degeneration and osteoarthritis. In addition to having non-impaired upper and lower extremity joint range of motion, restoration of neuromuscular strength and power are important to meet the dynamic joint stability requirements of each patient. Plyometric tasks related to this end must be modified from patient-to-patient to match the eccentric, stretch-shortening cycle requirements needed to restore abilities deemed essential to quality of life (LaStayo et al. 2003b) (Fig. 6.12). Even older patients who lack intense jumping and single-leg landing functional needs still likely require robust stair-climbing, propulsive walking or running gait, or quick and coordinated reaching and grasping or directional change needs in addition to effective neuromuscular responses to sudden perturbations associated for fall prevention or vocational/athletic injury or reinjury prevention. When plyometric exercise intensity increases, it is important that both the physiotherapist and patient monitor for maintenance of pain-free active joint range of motion. Planned use of aquatic therapy experiences can facilitate cardiovascular conditioning, active joint mobility and musculotendinous extensibility, anaerobic-aerobic metabolic system interval training, and balance training within the safe confines of a swimming pool. When used prescriptively to ameliorate joint loads between high-intensity and high-impact training sessions, the aquatic therapy environment can provide the respite needed for biomechanically loaded intra-articular fracture region tissues to recover and remodel. As the patient transitions from end-stage rehabilitation to more vocational or sport-specific training and conditioning, physiotherapist are advised to perform several functional tests at key intervals, not just to determine bilateral equivalency for more quantitative distance and timing parameters but also to verify similar qualitative assessments of a willingness to undertake sudden joint loading without apparent fear, favoring, or avoidance. Self-efficacy is an important behavioral construct to develop particularly when linked with tasks specific to patient needs (Brand et al. 2013). Too often self-efficacy developed performing less intense movement tasks creates a false sense of preparedness for when the patient is confronted with more challenging, less pre-planned, more chaotic tasks (Ghazi et al. 2018).

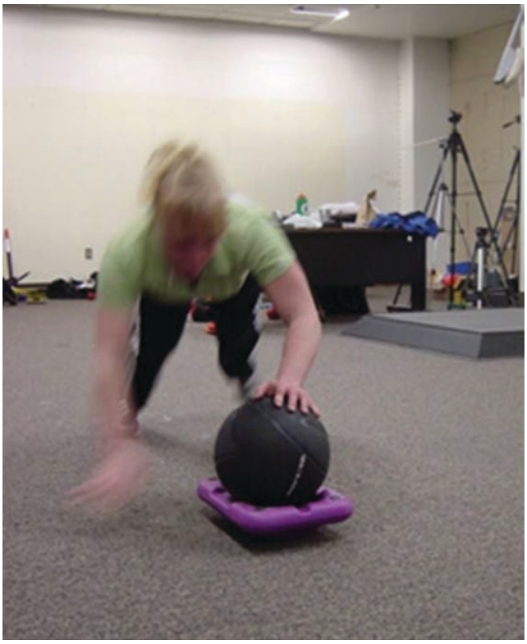


Fig. 6.12 Upper extremity push-up movement with quick side-to-side loading stimulates sudden concentric-to eccentric neuromuscular activation transitions and dynamic upper extremity joint stability

6.15 Objective and Subjective Function Assessments

Objective lower extremity region functional testing ranges from more static movements such as single-leg squats (Crossley et al. 2011; Räisänen et al. 2016) to more dynamic multi-planar single-leg hop for distance and time tasks for younger more active patients with a history of lower extremity intra-articular joint fracture (Fitzgerald et al. 2001; Manske and Reiman 2013) to less intense functional tests such as the timed up and go (time that a person takes to rise from a chair, walk 3 m, turn around, walk back to the chair, and sit down) and the 6-min timed walk test (total walking distance covered in 6 min) for older patients. Functional tests to validate safe upper extremity function are less well understood. A few examples include the sidearm medicine ball throw and the backward overhead medicine ball throw which evaluate integrated trunk and upper extremity function and the seated shot put, which more specifically evaluates upper extremity function (Manske and Reiman 2013). Subjective or perceived function information should include joint-specific inventories such as the Knee Injury and Osteoarthritis Outcome Score (KOOS) or the International Knee Documentation Committee Subjective Knee Evaluation (IKDC 2000), Tegner Activity Scale, and Marx Activity Scale for the knee (Marx et al. 2001; Nguyen et al. 2016; Tegner and Lysholm 1985); the modified Harris Hip Score or Hip Outcome Score for the hip (Gupta et al. 2016); the Foot and Ankle Ability Measure, Foot Function Index, Foot Health Status Questionnaire, Lower Extremity Function Scale, or Sports Ankle Rating System or ankle lunge test for the foot and ankle (Martin and Irrgang 2007; Simondson et al. 2012), the Constant score, ASES, UCLA, and Wolfgang's Criteria, the Shoulder Pain and Disability Index (SPADI), and the Simple Shoulder Test (SST) for the shoulder (Placzek et al. 2004); the Elbow Self-Assessment Score for the elbow (Beirer et al. 2017); or the Michigan Hand Outcomes Questionnaire for the hand (McPhail et al. 2012). Use of these more joint-specific inventories should be combined with regional indices such as the Disabilities of the Arm, Shoulder and Hand (DASH) Survey, Short Form-36 or Short Form-12, and other quality-of-life-related measurements to obtain a more holistic appraisal of the impact of intra-articular fracture and surgical or rehabilitation intervention on patient recovery.

6.16 Sufficient Follow-up

Nothing spoils successful surgical options like long-term follow-up! Long-term follow-up, however, is essential to ensuring preserved joint function. Most surgeons recommend following patients who have sustained lower extremity extra-articular fractures (with uneventful healing) radiographically for 3–6 months and clinically for 6 months. Many surgeons cease radiographic and clinical follow-up of extra-articular fractures by 6 months (Ricci et al. 2016). Longer time periods should, however, be considered following intra-articular fractures. If the orthopedic surgeon suspects any potential for early degenerative changes or osteoarthritis, they should consider following the patient for more than 12 months. In addition to following up to confirm fracture site healing and articular surface congruency integrity, comprehensive clinical examination should include assessments of joint functionality, objective and subjective joint movement assessment, and patient-specific essential functional task capability. It is also important to evaluate the influence of patient care on quality-of-life changes and to determine if they are satisfied and if intervention expectations have been met.

6.17 Conclusion

Effective intra-articular fracture management can have a significant positive influence on patient quality of life. In addition to assessing joint space integrity using standard radiographs and clinical examination, functionally relevant performance tests, general health inventories, and joint- or region-specific perceived function appraisals should also be performed. Intra-articular fractures require careful and comprehensive care planning throughout all phases of the rehabilitation process. Patient outcome expectations and quality-of-life values should be understood clearly during planning, and patients may need to be advised to modify vocational or sports pursuits to better preserve long-term joint health and function.

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Arthroscopic Treatment Vs. Open Surgery in Intra-articular Fractures

7

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The first knee joint arthroscopy was performed in 1912. Although the authors used a laparoscope that had been developed by a physician, they were the pioneers who introduced the term 'arthroscopy' into the orthopaedic literature. From 1912 until the present, the considerable technical development that has occurred has allowed orthopaedic surgeons to perform arthroscopic-assisted procedures in a variety of joint disorders (Table 7.1). Since the mid-1980s, moving beyond being a purely diagnostic procedure, arthroscopic-assisted correction of joint conditions has evolved into a therapeutic modality, as it offers minimally invasive usage, decreases blood loss and the duration of surgery, reduces complications, and offers an early return to normal daily life (Passler and Yang 2012). The procedure is most often used in knee conditions, but subtalar, ankle, hip, carpometacarpal, wrist, elbow, and shoulder joints are additional joints that can be visualised and undergo intervention via arthroscopically assisted procedures. In this chapter, the general advantages of arthroscopic surgery for different intra-articular fractures are presented.

Table 7.1 The main timeline of arthroscopic development during the twentieth century (Passler and Yang 2012)

1912	Danish surgeon Severin Nordentoft presented a paper on endoscopic findings within the knee using a technique that he termed 'arthroscopy'
1918	Japanese professor Kenji Takagi examined a cadaver knee with a cystoscope
1921	Swiss physician Eugen Bircher performed an arthroscopy using an abdominal laparoscope
1931	Takagi developed the No. 1 arthroscope, a 3.5 mm instrument that would become the model for present-day instruments. Dr. Burman published the results of his investigation in the historical paper 'arthroscopy or the direct visualisation of joints'
1959	Watanabe developed sophisticated instruments using electronics and optics, and his No. 21 arthroscope became a model for production
1962	Watanabe performed the first partial meniscectomy in Japan
1972	Dr. Joyce taught the first arthroscopy course in the USA at the University of Pennsylvania
1974	Dr. Richard O'Connor performed the first partial meniscectomy in North America. The International Arthroscopy Association was founded
1982	The Arthroscopy Association of North America was established

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Surgical intervention in intra-articular fractures using arthroscopy is a relatively recent procedure than treatments of other disorders using this technique. Direct visualisation and assessment of the reduction is not the only rationale behind arthroscopic-assisted articular fracture fixation procedures. With current imaging modalities, the assessment of intra- or periarticular pathologies related to the trauma is not necessarily possible, because chondral lesions, small meniscal tears, intra-articular loose bodies, and partial or total but non-displaced intra-articular ligamentous structure injuries are not visible with early posttraumatic imaging techniques due to the distorted anatomy and presence of haematoma. Arthroscopic direct visualisation of a joint allows the overall assessment of the articular structures and, if possible, enables the surgeon to address the injuries in the same session or, if not, plan for a secondary intervention.

Without a doubt, anatomic reduction and stable articular fracture fixation are the primary goal of all surgical interventions. To achieve this goal, several debilitating and painful operations with extensive incisions and techniques have been described. Open reduction and internal plating and external fixation through classic open incisions require extensive soft tissue dissection, periosteal stripping, and the evacuation of fracture haematoma, which can result in delayed union or non-union or other complications (Fisher and Hamblen 1978; Olerud and Karlström 1972). Over the last two decades, there has been an increasing effort to minimise soft tissue dissection; minimally invasive techniques, low profile implants, and reduction devices have all been developed to achieve this goal (Ronga et al. 2010). In selected cases arthroscopic-assisted fracture reduction using minimally invasive fixation methods will become preferred to traditional interventions. However, surgeons can only use this technique after a long learning curve. Assessment of a traumatic joint is not easy, because fracture haematoma, displaced intra-articular surfaces, and a distorted anatomy make it difficult to evaluate and address the problem appropriately. Thorough preoperative planning, an understanding of fracture characteristics, and surgical skills that can only be gained after long training is needed (Dei Giudici et al. 2015).

Although a small amount of angulation and translation of the long bones after surgery is accepted, a displacement of more than 2 mm is unacceptable for an articular fracture (El-Sayed and Ragab 2009; Rapariz et al. 1996). The intraoperative assessment of a reduction using an image intensifier is useful, but it may not allow the surgeon to estimate the amount of displacement, because the articular surface is coated with a chondral layer, which is not visible using the image intensifier (Dei Giudici et al. 2015; Ercin et al. 2013; Haklar et al. 2009; Laffosse et al. 2007). Such situations have tended to favour arthrotomy, which is currently suggested for use in comminuted fractures. Arthroscopy, however, has the same goals but involves less capsule dissection. Moreover, its zooming property allows surgeons to evaluate displacements at magnifications of up to 40 times the actual size.

As a minimally invasive choice, percutaneous fixation of minimally displaced articular fractures is a widely used surgical method. However, in some cases, it is essential to position the screw close to the articular surface, and screw penetration into the joint can be underestimated using an image intensifier alone (Ercin et al. 2013; Yamamoto et al. 2003; Yang et al. 2010). This problem particularly occurs in cases where the physis is still open; damage to both the physis and articular surface can be disastrous in growing bone. Lafosse et al. (2007) advocated the use of arthroscopy in adolescent pilon type III and IV Salter-Harris fractures to verify the reduction and prevent intra-articular screw penetration. Götz and Schulz (2013) advocated the use of hip arthroscopy instead of three-dimensional fluoroscopic-based navigation to assess intra-articular screw penetration during surgery for displaced acetabular fractures performed through the ilioinguinal approach.

Arthroscopic-assisted procedures after trauma have been reported in fractures of the following joints: calcaneus and talus, ankle, knee, hip, thumb, wrist, elbow, and shoulder. Although a definitive contraindication or indication has yet to be described for the use of arthroscopy, it has generally been used to treat minimally displaced or depressed articular fractures with good soft tissue stock (Honkonen 1994). General contraindications include a lack of sufficient capsule or bone stock to maintain the fluid in the joint, severely comminuted fractures, and open articular fractures (Bartlett et al. 1998; Tejwani et al. 2006; Yamamoto et al. 2003). However, these are not absolute contraindications and final decision is related to the experience of the surgeon and the type of fracture (Ercin et al. 2013; Tejwani et al. 2006; Wood et al. 2014).

7.1 Calcaneus and Talus Fractures

Arthroscopic-assisted fracture reduction and internal fixation (ARIF) can be used for the treatment of calcaneus fractures instead of open procedures due to the improved visualisation of the fragments compared with fluoroscopy alone (Gavlik et al. 2002). Yeap et al. (2016) compared the radiological and clinical outcomes of open reduction and internal fixation (ORIF) with plates and ARIF with percutaneous screws. They found no difference between the two groups in terms of Böhler’s and Gissane’s angles. However, the authors concluded that the ARIF group was ‘able to undergo surgery earlier, return faster, and return to work earlier’.

There are very limited data in terms of the use of ARIF for the treatment of talar fractures. Funasaki et al. (2015) successfully treated a patient who had sustained a Hawkins type I fracture of the lateral process of the talus. Although the authors advocated the use of ARIF in this type of fracture, they also restricted its use to this type alone, because it might be difficult to achieve arthroscopic reduction and fixation in comminuted fragments. Wood et al. (2014) successfully performed ARIF using percutaneous fixation on a patient who sustained a Hawkins type II talar neck fracture. The authors emphasised the importance of preserving the soft tissue and avoiding iatrogenic compromise of the precarious blood supply as far as possible in these fractures to avoid avascular necrosis of the talar dome.

7.2 Ankle Fractures

There are numerous reports on arthroscopic-assisted treatment of acute foot and ankle trauma, but there is no universal agreement in terms of specific indications in this area. These fractures are frequently accompanied by ligamentous and chondral injuries. Although the accompanying injuries, including deltoid ligament injuries and chondral defects, have been reported to be completely evaluated via arthroscopy, the indications for surgical treatment are debatable (Bonasia et al. 2011). However, syndesmotic instability resulting from insufficient intraoperative assessment, malreduction, and fixation is not uncommon (Miller et al. 2013). Sri-Ram and Robinson (2005) claimed that ankle arthroscopy could be considered part of the management of syndesmotic injuries and can increase the accuracy of syndesmotic reduction because it enables direct inspection of the incisura.

Similar to syndesmotic injuries, malleolar fractures develop after a torsional or rotational force mechanism and are often accompanied by ligamentous or cartilaginous damage to the joint (Fig. 7.1). Ono et al. (2004) performed ARIF with percutaneous fixation in 105 patients who had sustained a medial malleolar fracture. They concluded that the inclusion of arthroscopy in the therapeutic procedure for fresh malleolar fractures produced reliable surgical results, because the accompanying injuries, which were not detected on preoperative radiographs, could be simultaneously dealt with. Turhan et al. (2013), in a randomised comparative study comparing ARIF and conventional ORIF for the treatment of medial malleolar fractures, stated that with the use of arthroscopic-assisted techniques in the fixation of isolated medial malleolar fractures, surgeons evaluated the intra-articular surface and reduction and that this may be of value in improving the clinical outcomes compared with conventional surgical treatment.

ORIF with minimally invasive plate osteosynthesis in pilon fractures has been shown to produce excellent results (Bonasia et al. 2011; Ronga et al. 2010). Moreover, there is not enough evidence to conclude that ARIF of complex pilon fractures is

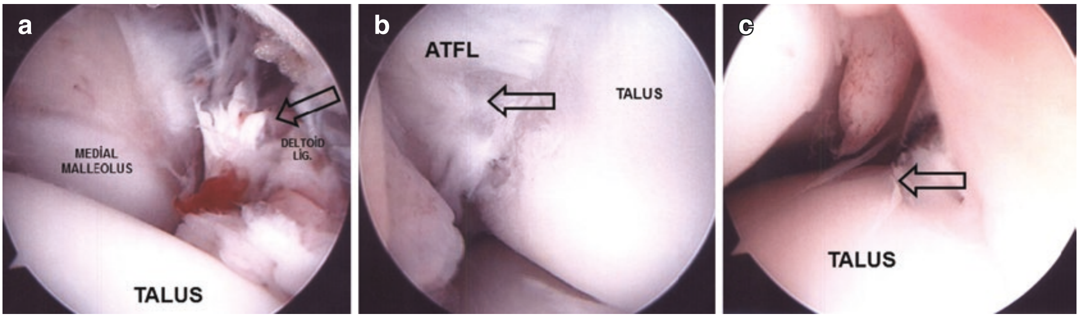

Fig. 7.1 (**a**) Deltoid ligament rupture in combination with an isolated lateral malleolus fracture (black arrow). (**b**) Syndesmotic ligament (*ATFL* anterior tibiofibular ligament) rupture (black arrow) accompanying a medial malleolus fracture. (**c**) Chondral stripping (black arrow) in a patient who has sustained a medial malleolus fracture

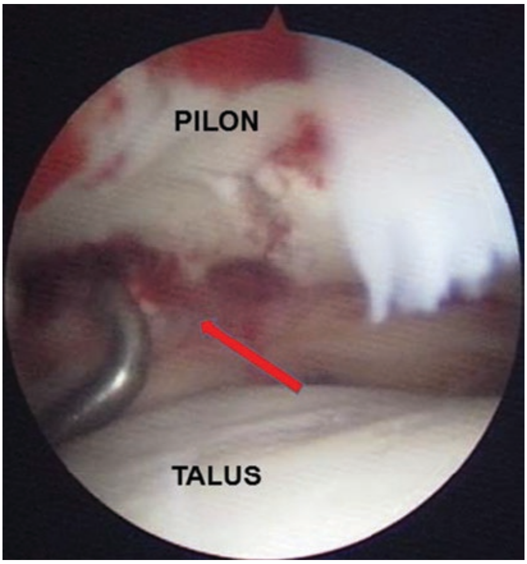

Fig. 7.2 Chondral depression in a patient sustaining a type 43-B2.2 pilon fracture (red arrow)

superior to ORIF (Braunstein et al. 2016; Gonzalez et al. 2016). However, split-depression fractures (die punch fractures) of this area require arthrotomy. Previously, an arthroscopic-guided technique that uses a modified form of the targeting device used for anterior cruciate ligament surgery to centre the depressed zone and reduce the chondral lesion through a window by tapping has been described (Poyanli et al. 2012) (Fig. 7.2). Subsequently, Lonjon et al. (2015) used the same technique and reported that it could decrease the complications related to open reduction techniques and that the achievement of fracture reduction and maintenance of joint congruity in 43-B2.3 and 43-B2.2 fractures under direct visualisation is possible with this technique. Successful ARIF of triplane fractures of the distal tibia and Tillaux fractures in adolescents and children have also been reported (McGillion et al. 2007; Panagopoulos and van Niekerk 2007).

7.3 Knee Fractures

Because the knee was the first joint to be visualised with an endoscope, it is the best-known joint for the treatment of fractures, including the tibial plateau, tibial eminentia, patella, and femur condyles. Schatzker types I, II, and III fractures are commonly treated with arthroscopic guidance. In addition, type IV and V fractures have been treated in selected cases with success (Krause et al. 2016; Wang et al. 2016). Plateau fractures are often concomitant with injuries to the collateral and cruciate ligaments, menisci, and sometimes to the surrounding nerves and arteries (Bennett and Browner 1994; Wang et al. 2016). Apart from the aforementioned advantages, arthroscopic-guided treatment of these fractures also has the advantage of being able to free menisci that have been trapped in the fracture gap (Bennett and Browner 1994). Moreover, recently published studies have shown that ARIF leads to better radiological results than ORIF. Concomitant intra-articular soft tissue lesions can be addressed more successfully during ARIF. Krause et al. (2016) used the term ‘fracturoscopy’ in reference to ARIF in their study comparing the radiological results of complex tibial plateau fractures treated with ORIF and then assessed with arthroscopic guidance. The authors assessed 17 patients, where arthroscopy had been performed after ORIF of the fracture. In ten patients, a persistent displacement of more than 2 mm was detected and re-reduced under direct visualisation via arthroscopy. The authors concluded that fracturoscopy was preferable to fluoroscopy in the assessment of fracture reduction, particularly in terms of complex fractures of the postero-latero-central region of the tibial plateau. Postoperative computed tomography scans revealed anatomic reduction in all cases (Fig. 7.3).

For isolated tibial eminentia fractures, arthroscopic-assisted fracture fixation is currently the treatment of choice (Zhang et al. 2017), because arthroscopic surgery is less invasive and allows for earlier mobilisation than other techniques (Memisoglu et al. 2016; Pape and Giffin 2005). Although reported fixation techniques vary, pullout sutures using arthroscopic guidance are the most recommended technique, particularly in children (Leeberg et al. 2014; Memisoglu et al. 2016; Pape and Giffin 2005; Zhang et al. 2017) (Fig. 7.4). Through the use of a transquadricipital portal, effective tibial eminence fracture fixation can be achieved and anterior cruciate

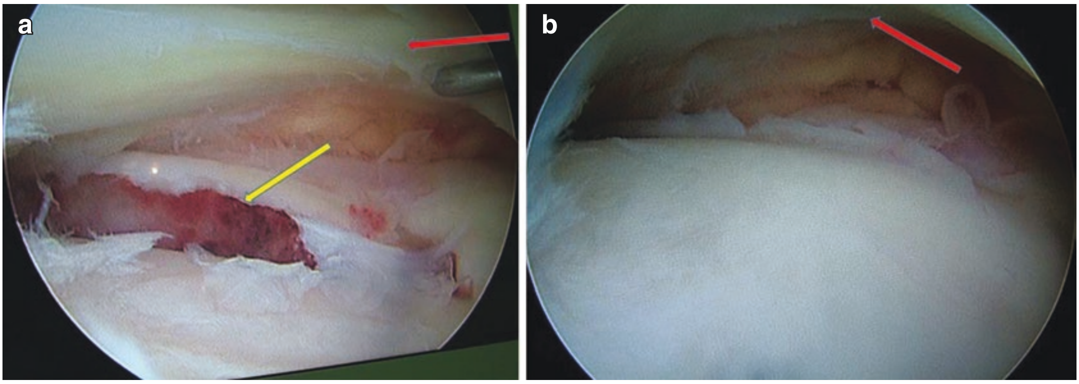

Fig. 7.3 (**a**) Schatzker type III depression fracture of lateral tibia plateau (red arrow, lateral meniscus; yellow arrow, fracture line and depressed posterolateral tibia plateau). (**b**) Reduced and fixed fracture after elevation and grafting the fracture zone (red arrow, lateral meniscus)

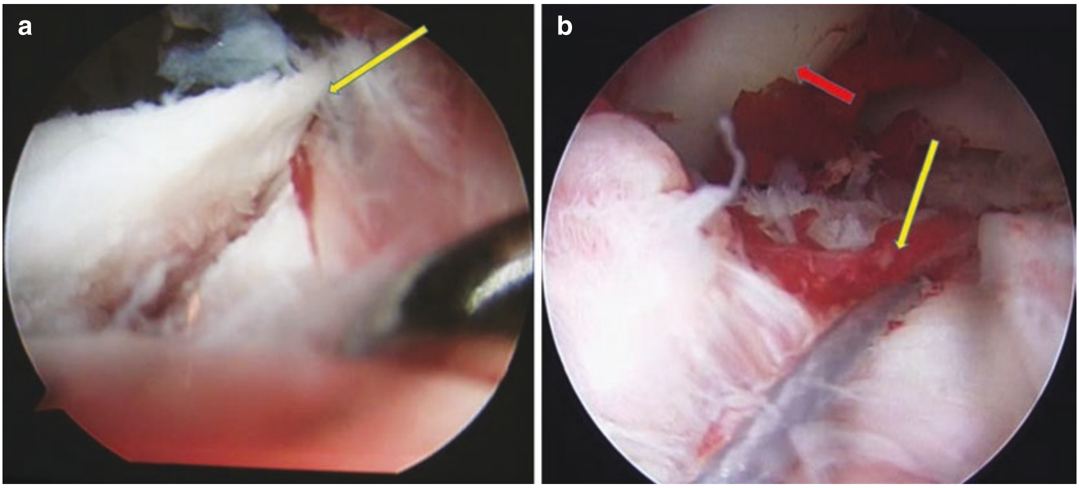

Fig. 7.4 (**a**) View of a tibial eminentia fracture from anterolateral portal (yellow arrow, elevated anterior part of eminentia). (**b**) Eminentia reduced and fixed with a pullout suture technique (yellow arrow) (red arrow, medial femoral condyle)

ligament laxity status can be determined under direct arthroscopic observation (Doral et al. 2001). Moreover, posterior cruciate ligament avulsion fractures from the tibial plateau have been treated with ARIF, and the results are reported as promising. Yoon et al. (2016), in their series of 18 patients, reported that ARIF of these fractures yielded good clinical and radiological outcomes, including satisfactory stability and fracture healing.

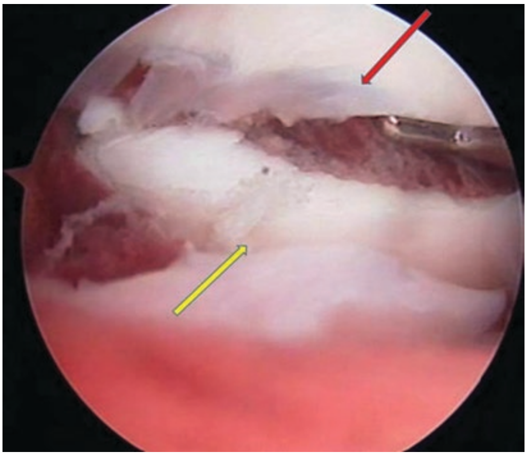

Fig. 7.5 View of a Müller type III (Hoffa fracture) medial femoral condyle fracture from anterolateral portal before reduction (yellow arrow, posterior part of medial condyle; red arrow, anterior part of medial condyle)

Distal femur fractures type BI, BII, and BIII (Hoffa), according to the Müller classification system, can be treated with ARIF, as they are articular fractures, and screw penetration to the joint poses an increased risk in these fractures (Demirel et al. 2006; Goel et al. 2016) (Fig. 7.5). Given enough surgical skill, ARIF has been reported to be an effective, safe, and minimally invasive surgical technique that can also address accompanying injuries in these patients (Ercin et al. 2013).

Currently arthroscopic-assisted retrograde intramedullary nailing for type 33-C2 comminuted metaphyseal distal femur fractures with articular extension can also be performed. We advocate this technique as intramedullary nailing enables less soft tissue dissection and arthroscopic guidance allows us to obtain precise reduction. After obtaining a provisional reduction of articular extension under fluoroscopy, arthroscopy can be performed with ease. Moreover, our experience with this technique has demonstrated that in most cases the nail tip can be positioned to close to the chondral level if assessed only with fluoroscopic guidance (Fig. 7.6).

ORIF with 'tension wiring' remains the gold standard treatment option for patellar fractures. Although an anatomical reduction can be achieved during ORIF of these fractures, articular step-off, displacement, and cartilage loss can

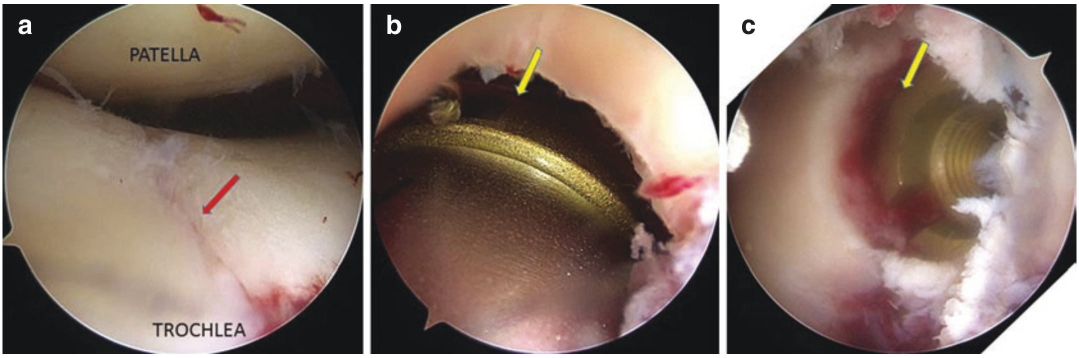

Fig. 7.6 A 35-year-old male sustained AO-33-C2 distal femur fractures with articular extension. (**a**) Red arrow showing precise reduction after fixation with three free screws. (**b**) Also fluoroscopy indicates enough tapping; yellow arrow shows tip of the nail still at the chondral level. (**c**) After additional tapping yellow arrow shows tip of the nail passed beyond the chondral layer

commonly occur (Haklar et al. 2009). ARIF allows the surgeon to assess the reduction with a perfect view and perform debridement if necessary. With the application of cannulated screws, required fracture site compression can be obtained. Using cannulated screws, ARIF has been reported to be easy, less invasive, and reliable and provides good clinical results for the treatment of transverse patellar fractures (El-Sayed and Ragab 2009).

7.4 Hip Fractures

Details of the outcomes of ARIF of acetabular and femoral head fractures in the literature are very limited. Reported hip fractures treated with arthroscopic guidance mainly comprise Thompson and Epstein type III comminuted acetabular fractures and Pipkin type I and II femoral head fractures. Rather than perform reduction and fixation of the fracture, removal of fragments or treatment of labral pathology has been performed.

Yamamoto et al. (2003) were the first to describe arthroscopic-assisted percutaneous fixation of a fracture of the weight-bearing region of the acetabulum in one patient. Subsequently, Yang et al. (2010) reported on two patients treated with arthroscopic-assisted percutaneous fixation who had sustained an anterior wall fracture and anterior column fracture that subsequently extended to the dome. Both Yamamato et al. and Yang et al. claimed the use of this technique in minimally displaced fractures that can be reduced by closed means.

ARIF of the femoral head has been reported to be successful in Pipkin type I and II fractures (Matsuda 2009; Park et al. 2014a, b). However, in a series of 11 joints, arthroscopic-assisted fracture fixation in severely displaced femoral head fractures and in patients with unstable posterior acetabular wall fractures was reported to be technically almost impossible (Yamamoto et al. 2003).

With current techniques and the introduction of new devices, hip arthroscopy is a possibility as a complementary treatment for stable fractures but is almost never a first-choice procedure for unstable fractures or where there is a lack of sufficient soft tissue support or bone stock. The traditional technique of ORIF still remains the gold standard for the definitive treatment of displaced acetabular fractures.

7.5 Bennett Fractures

The increasing popularity of arthroscopic techniques in trauma surgery has prompted orthopaedic surgeons to develop a technique for ARIF of Bennett fractures (Culp and Johnson 2010; Pomares et al. 2016). Culp and Johnson (2010) used a 1.9 mm arthroscope to assess the trapeziometacarpal joint through one radial and one ulnar portal. Moreover, Pomares et al. (2016) used a 2.4 mm arthroscope to compare the radiological and clinical results of ORIF and ARIF for the treatment of Bennett fractures. The authors performed ARIF with percutaneous screws in 11 patients and conventional ORIF in 10 patients. Although no intra-articular screw migration or inadequate reduction was detected in the ARIF group, two inadequate reductions and four intra-articular screw migrations were detected in the ORIF group. The authors advocated the use of arthroscopy for Bennett fractures, as it provided anatomical joint surface reduction and a simpler postoperative course with, in particular, a lower postoperative complication rate and shorter immobilisation time, and it allowed the patient to resume normal daily activities. Successful arthroscopic-assisted reduction and percutaneous fixation of linear fractures of the trapezoid bone have also been reported (Wiesler et al. 2007).

7.6 Wrist Fractures

Although the wrist is a narrow joint compared with the shoulder and knee, ARIF of wrist fractures is widely performed. Ruch et al. (2004) performed arthroscopic-assisted fracture reduction and external fixation in 15 patients and fluoroscopic-assisted fracture reduction and external fixation in 15 patients. They compared the functional and radiological outcomes of arthroscopic-assisted vs. fluoroscopic-assisted reduction and external fixation of distal radius fractures. They found that supination, flexion, and extension of the wrist were better in the arthroscopic-assisted group. Moreover, they emphasised the advantage of arthroscopy in allowing them to better evaluate ulnar-sided injuries and subsequently address them. In a similar study, Varitimidis et al. (2008) compared the radiological and clinical results of arthroscopically assisted vs. fluoroscopically assisted reduction and external fixation of comminuted distal radius fractures. They included 20 patients in each group and, after a 24-month follow-up period, found results similar to those of previous authors, in that supination, flexion, and extension of the wrist were better in the arthroscopic-assisted group. The authors stated that the addition of arthroscopy to the fluoroscopic-assisted treatment of intra-articular distal radius fractures improves the outcome.

Open reduction and stabilisation of trans-scaphoid perilunate fracture dislocations (PLFDs) have been shown to be better than non-surgical treatments. However, restricted flexion and extension of the carpal arc after open surgery of these complex injuries remain a major problem (Krief et al. 2015). ARIF has been performed for the treatment of trans-scaphoid PLFDs to overcome this problem, as this procedure significantly decreases the invasiveness of the treatment. Oh et al. (2017) reported a study to compare the results of open surgery and arthroscopic-assisted surgery. They performed ARIF in 11 patients and ORIF in nine patients. After a minimum follow-up of 24 months, the flexion-extension arc and disabilities of the arm, shoulder, and hand scores were significantly better in the ARIF group. However, other results, including mean scapholunate angle, radiolunate angle, lunotriquetral distance, and grip strength, were similar in both groups.

Arthroscopic-assisted reduction and percutaneous fixation of scaphoid fractures has been performed, but its superiority over conventional methods or fluoroscopically assisted percutaneous fixation has yet to be proven (Atesok et al. 2011). Clementson et al. (2015) evaluated the clinical and radiological outcomes after non-surgical treatment and arthroscopic-assisted screw fixation of acute non- or minimally displaced scaphoid waist fractures in a randomised controlled trial. They found conservative treatment to be superior to arthroscopic-assisted percutaneous fixation, particularly in minimally or non-displaced fractures after a minimum of 4 (mean = 6 years) years of follow-up. However, Slade et al. (2008) advocated the use of arthroscopic-assisted percutaneous fixation for the treatment of displaced scaphoid fractures so as not to disrupt the already limited blood supply to the bone.

7.7 Elbow Fractures

Arthroscopic-assisted procedures have been used in the elbow joint, because the challenging anterior neurovascular anatomy of the elbow makes it difficult to access the anterior structures through an anterior approach. Coronoid, radial head, lateral condyle, and capitellum fractures are all amenable to arthroscopic or arthroscopically assisted fracture fixation (Fink Barnes et al. 2015). Lee et al. (2015) treated Regan-Morrey type I, II, and III coronoid fractures successfully under arthroscopic guidance. Michels et al. (2007) advocated the use of arthroscopic-assisted percutaneous fixation for the treatment of Mason type II radial head fractures, as it allowed a better reduction of the fracture.

Hausman et al. (2007) performed arthroscopic-assisted percutaneous fixation in six skeletally immature patients with lateral humeral condyle fractures and advocated its use in these fractures, as it decreases the risk of malunion or avascular necrosis.

7.8 Shoulder Fractures

Although widely used for the treatment of humerus fractures, antegrade intramedullary nailing has been criticised for its potentially deleterious effect on shoulder function, caused by trauma to the supraspinatus at the nail insertion point (Kim et al. 2007). As a solution to these problems, Lill et al. (2012) performed arthroscopic intramedullary nailing of these fractures and compared their results with nailing using a conventional method. They also repaired previously detected rotator cuff injuries and bicipital tendon injuries in all patients in the arthroscopic group which had occurred prior to surgery. They concluded that this method was effective for the preservation of the rotator cuff and could provide equal replacement and functional results similar to those of open technique.

The shoulder joint is surrounded by complex neurovascular structures and open reduction methods for fractures of this joint require large soft tissue dissections which may lead to an impaired blood supply to the bony fragments and postoperative stiffness or weakness. The axillary nerve is also at risk during the both extensive and minimally invasive open surgical approaches. However, ORIF of glenoid fractures has been reported to be satisfactory despite its potential complications. Moreover, the successful treatment with ARIF of Ideberg type I, II, and III fractures of the glenoid have been reported (Helling et al. 2002). Yang et al. (2011), in their series of 18 cases of patients who sustained Ideberg type III fractures, used ARIF with percutaneous fixation to treat these fractures. They advocated the use of ARIF in these fractures because it was safe and less invasive, allowed surgeons to repair concomitant rotator cuff injuries, and allowed surgeons to obtain perfect reduction. However, successful treatment with ARIF of more complicated glenoid fractures has also been reported (Qu et al. 2015). Arthroscopic-assisted fixation of greater tuberosity fractures of the humerus have also been reported to be satisfactory. In a series of 40 patients with an average of 32 months of follow-up, ARIF was shown to be useful and allowed the surgeon to achieve satisfactory clinical and radiological results (Ji et al. 2017). Because of the aforementioned advantages of ARIF in the shoulder joint, arthroscopic-assisted fixation of unstable distal clavicle fractures (Neer type II) has been performed in two studies using different stabilisation and fixation methods under arthroscopic guidance. The authors of both studies reported excellent clinical and radiological results (Cisneros and Reiriz 2015; Kraus et al. 2015).

7.9 Conclusion

Although the literature lacks evidence to compare long-term radiological and clinical results between arthroscopic-assisted fracture reduction and open reduction, the use of arthroscopy in trauma management is increasing in popularity. Arthroscopic-assisted fracture reduction procedures possess excellent direct and overall assessment of the joint and allow surgeons to obtain precise reduction, perform debridement, intervene to treat concomitant joint injuries, and focus on correcting other pathologies in accordance with fracture healing. Moreover, this procedure has become the gold standard method of surgical treatment in a variety of articular fractures. Notwithstanding the above-mentioned advantages, there are some limitations and complications. Assessment of a traumatic joint is not easy, as fracture haematoma, displaced intra-articular surfaces, and a distorted anatomy make it difficult to evaluate and address problems appropriately. Thorough preoperative planning, developing a thorough understanding of fracture characteristics, and surgical skills that can only be gained after a long training period are required. Without the mandatory surgical skills and arthroscopic devices, fluid extravasation resulting in compartment syndrome, neurovascular damage, and inappropriate treatment of the injury, as well as several other potential complications, may be unavoidable. Arthroscopic-assisted fracture fixation is promising. However, further controlled, randomised prospective studies are needed to draw definitive conclusions.

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Part II

Arthroscopic Management of Shoulder and Elbow Fractures

8 Arthroscopic Treatment of Acromioclavicular Dislocations

Ali Cavit, Haluk Ozcanli, and A. Merter Ozenci

8.1 Introduction

Acromioclavicular (AC) joint serves as a primary connection between the upper appendicular skeleton and the axial skeleton. AC joint is commonly involved in traumatic injuries to the shoulder, and these injuries force surgeons in the diagnostic and therapeutic sense. Although AC joint injuries are seen especially in young athletes, they can also be seen in other age groups after traffic accidents and falls. Sports such as football, ice hockey, rugby, and wrestling are among the main reasons for AC joint injuries and more commonly seen in male athletes than in females (Hibberd et al. 2016; Pallis et al. 2012). This injury constitutes 30–50% of athletic shoulder injuries and represents 8% of all joint dislocations in the body (Pallis et al. 2012). But these values do not reflect the true incidence, as many cases have been overlooked.

8.2 Anatomy and Biomechanics

The AC joint is a diarthrodial joint, and a thin, fibrocartilaginous, meniscus-like disc lies within the joint. In the first years of life, the articular surface is made up of hyaline cartilage and later transforms to fibrocartilage, degenerates over time, and becomes incompetent in most individuals beyond fourth decade (DePalma 1959). In superior-inferior plane, the average size of the AC joint is approximately 9 mm and 19 mm in anterior-posterior plane. And the width of the AC joint ranges from 1 to 3 mm (Bonsel et al. 2000).

The AC joint has both static and dynamic stabilizers. A thick joint capsule, four horizontally oriented AC ligaments (anterior, posterior, inferior, and superior ligaments), and the coracoclavicular and coracoacromial ligaments constitute the static stabilizers. The dynamic stabilizers include the deltoid and trapezius muscles. Pectoralis major and subclavius muscles have their primary effects on the sternoclavicular joint.

The AC joint capsule and the AC ligaments are the principle restraints of anteroposterior translation of the distal clavicle (Fukuda et al. 1986). The posterior and superior AC ligaments are the most significant contributor to joint stability in horizontal plane (Klimkiewics et al. 1999). In their biomechanical studies, Corteen and Teitge (2005) showed that 1 cm distal clavicle resection results in 32% increase in posterior translation compared with intact cadaveric joint.

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The vertically oriented coracoclavicular (CC) ligaments, including the conoid ligament medially and the trapezoid ligament laterally, contribute to the stability of the AC joint in vertical plane. These ligaments prevent superior and inferior translation of the clavicle. The CC ligaments also guide synchronous scapulohumeral motion by attaching the clavicle to the scapula, as well as AC joint strengthening function. The CC ligaments originate from superior surface of the coracoid process posterior to the pectoralis minor attachment, course superiorly, and insert inferior surface of the lateral aspect of clavicle with an average length of 13 mm (Salter et al. 1987). The distance of the distal end of clavicle to the conoid and trapezoid ligaments varies according to the sex; the average distance for conoid ligament is 47.2 ± 4.6 mm in males and 42.8 ± 5.6 mm in females; it is 25.4 ± 3.7 mm in males and 22.9 ± 3.7 mm in females for trapezoid ligament (Rios et al. 2007).

Fukuda et al. (1986) reported that the primary restraints to superior translation of clavicle were AC ligaments in small displacements; and it was the conoid ligament in larger displacements. The trapezoid ligament was found to be the primary restraint to compression of the AC joint. Mazzocca et al. (2008) have demonstrated that with superior load to AC joint, the cascade of injury consistently started with conoid ligament failure followed by trapezoid ligament.

The AC joint has micromotion in all planes. Worcester and Green (1968) have described three types of motion in the AC joint: rotation along the long axis of the clavicle, abduction and adduction of the scapula on clavicle, and anterior and posterior displacement of the scapula on clavicle. Ludewig et al. (2004) demonstrated that the clavicle undergoes elevation (11–15 °) and retraction (15–29 °) with respect to thorax during arm elevation. The AC joint rotates approximately 5–8 ° in line with scapula during forward elevation and abduction. Scapular motion plays a major role in the motion of AC joint. Small movements of acromion in anteroposterior direction provide maintenance of the relationship between glenoid cavity and humeral head in shoulder flexion and abduction. These movements are restricted by CC ligaments. The AC joint should not be fixed either by fusion or hardware like screws, plates, etc., because the rotation of the clavicle is associated with arm elevation and scapular motion. Fixation of AC joint will eventually result in functional limitation in shoulder or hardware failure.

8.3 Mechanism of Injury

The AC joint injuries can be seen as a result of direct or indirect forces. The most common mechanism of injury is a direct trauma, caused by fall or blow to the lateral aspect of the shoulder with the arm in adduction. This acting force on shoulder causes inferior and medial displacement of the scapula and acromion. In the early stages of trauma, clavicle remains in its anatomical position. Further transmission of force initiates a cascade of injury that begins with AC joint capsule and ligamentous structures' failure, followed by rupture of CC ligaments. This condition is defined as complete AC joint dislocation. In cases of severe injury, disruption of muscular attachments of the trapezius and deltoid muscles from clavicle is observed. Indirect mechanisms of AC joint injuries are rare and may occur by falling on out-stretched hand or elbow in adducted position. This results in superior displacement of humeral head, leading to a pushing force against acromion.

8.4 Classification

The mechanism of AC joint injury was first described by Cadenet (1917), and Tossy et al. (1963) published a new classification system which forms the basis of today's most widely used system. In 1984, Rockwood (1984) developed a new classification system to categorize the degree as well as the direction of the injury. According to the Rockwood classification system, there are six types of AC joint injuries:

Type I: Sprain of the AC ligaments. Radiographically normal. Tenderness on the AC joint. CC ligaments are intact.

Type II: Complete tears of the AC ligaments. CC ligaments are intact. Unstable in anteroposterior plane, stable in superoinferior plane. Radiographic AC joint widening may be present.

Type III: Disruption of both AC and CC ligaments resulting in complete AC joint dislocation. Deltoid or trapezial fascia is usually intact. 25–100% increase in CC space compared to the contralateral side. Clavicle is unstable in both vertical and horizontal planes.

Type IV: Posterior displacement of the clavicle into or through the trapezius muscle and may tent posterior skin. Best seen on the axillary view. Often found incarcerated in this position at surgery.

Type V: More severe form of type III injury. Greater than 100% increase in radiographic distance between clavicle and coracoid process. Clavicle is often non reducible as it pierces deltotrapezial fascia.

Type VI: Rare. Inferior displacement of the distal end of clavicle. Usually result of a high energy trauma with multiple other injuries. Mechanism of injury is hyperabduction and external rotation of the arm. The distal clavicle ends up in a subacromial or subcoracoid position.

8.5 Clinical Evaluation

Clinical evaluation should be done in comparison with contralateral normal joint. In acute injuries, pain, tenderness and swelling at the AC joint are the main complaints. Significant deformity and stepping can be seen between distal end of the clavicle and acromion, especially in complete dislocations. Piano sign may be elicited with ballottement of the lateral end of the clavicle. In severe injuries, a hematoma may be present indicating the avulsion of the muscle attachments. It is important to evaluate the horizontal instability on the physical examination. Posterior displacement of the clavicle is assessed, while the acromion is stabilized with the other hand. Ipsilateral glenohumeral and sternoclavicular joints should be examined for accompanying injuries. The patient must also be assessed for neurovascular injury and fracture.

8.6 Radiographic Evaluation

Radiographical images should be obtained when AC joint injury is suspected in the patient's history and physical examination. Radiographic view of the contralateral normal joint should be taken for comparison. Anteroposterior, lateral, and axillary views are the standard views used for this purpose. The anteroposterior view is important in determining vertical instability, whereas the axillary view evaluates horizontal instability. But improved visualization of the AC joint can be obtained by the Zanca view (Zanca 1971). This view is performed with a 10–15 ° cephalic tilt of the X-ray beam and using only 50% of the standard shoulder anteroposterior penetration strength. Superimposition of the acromion on the distal clavicle can be avoided through using Zanca view. Stress views can be obtained to assess AC joint instability by holding weights in each arm. This is more useful in distinguishing type II injuries from occult type III injuries.

The AC joint width in the frontal plane (Zanca view) is normally 1–3 mm and decreases with age. An AC joint width greater than 7 mm in men and 6 mm in women is considered pathological. Bearden et al. (1973) reported that an increase of 25–50% in the CC distance relative to the normal side is suggestive of complete disruption of CC ligaments.

Magnetic resonance imaging can also be used in assessment of the stabilizing soft tissue structures (AC and CC ligaments, deltotrapezial fascia) and in clinical grading of dislocation.

8.7 Treatment

Various surgical treatment modalities of unstable AC joint injuries have been described for years in the orthopaedic literature. But in general there are four main surgical strategies:

1. Primary AC joint fixation with or without ligament reconstruction/repair
2. Primary CC fixation with or without AC ligament reconstruction/repair
3. Distal clavicular resection with or without CC ligament repair/coracoacromial ligament transfer
4. Muscle transfers with or without distal clavicular resection

All of these surgical strategies share a common goal of stabilization and realigning of the distal clavicle. This can be achieved anatomically with reproduction of conoid and trapezoid ligaments or nonanatomically with reproduction of a single CC ligament or using internal fixation hardware (Martetschläger et al. 2016). One of the most commonly utilized treatment methods is the use of metal hardware (K wire, hook plate, screws, etc.). However this method should be used with caution, as it can change the biomechanics of the AC joint, and high rates of failure of fixation and complications can be seen with these nonanatomic procedures (Chiang et al. 2010; Kienast et al. 2011; Norrell and Llewellyn 1965; Sethi and Scott 1976; Warth et al. 2013). Also, these procedures almost always need a second surgery for implant removal (Babhulkar and Pawaskar 2014; Johansen et al. 2011) (Figs. 8.1 and 8.2).

In the last 10–15 years, arthroscopically assisted treatment methods for unstable AC joint injuries have been developed and popularized with several advantages among open techniques using metal hardware (Baumgarten et al. 2006; Chernchujit et al. 2006; DeBerardino et al. 2010; Gille et al. 2013; Hosseini et al. 2009; Lafosse et al. 2005; Rolla et al. 2004; Wolf and Pennington 2001). One of the major advantages of these procedures is the possibility of detection and treatment of additional glenohumeral lesions. Concomitant glenohumeral injuries may be present in almost one third of the unstable AC joint injuries. Especially, the superior labrum, long head of biceps, and the rotator cuff are the affected structures (Arrigoni et al. 2014; Pauly et al. 2009, 2013; Tischer et al. 2009). Better cosmetic results with smaller incisions, minimal soft tissue dissection, and direct visualization of the

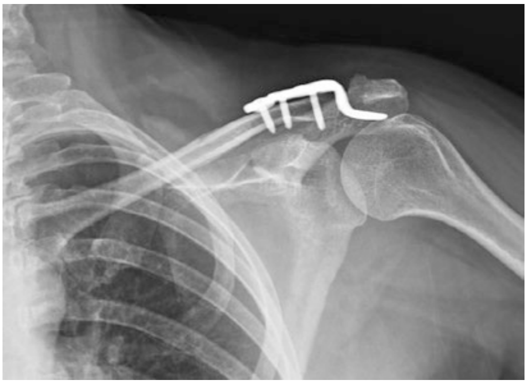

Fig. 8.1 Hook plate impinging on the humeral head which causes pain and limitation of shoulder abduction

Fig. 8.2 Second surgery is needed to remove hook plate

base of the coracoid are the other main advantages of the arthroscopic approaches (Wolf and Pennington 2001). Direct visualization is especially important when placing CC fixation systems, as it ensures the more accurate tunnel placement at the coracoid process. There is no need for obligatory implant removal in arthroscopic procedures, except for arthroscopically assisted Bosworth technique. Apart from the significant disadvantages of open surgery, hematoma, infection, and implant loosening are less common in arthroscopic procedures.

8.7.1 Arthroscopy-Assisted Techniques

Arthroscopic treatment of AC joint dislocations was first described by Wolf and Pennington in 2001. They used SecureStrand cable (Surgical Dynamics, Norwalk, CT) which is manufactured from an ultra-high-molecular-weight polyethylene fiber and used in spinal reconstructive procedures. This technique requires release of the middle and superior glenohumeral ligament to allow access to the base of the coracoid. They performed this technique in four patients (1 type V, 3 type III), and the preliminary results were excellent with no recurrences of the deformity (Wolf and Pennington 2001).

In 2004, Trikha et al. used polydioxanone-sulfate (PDS) cord in arthroscopy-assisted treatment of five patients with AC joint dislocation. They reported one slight loss of reduction in the follow-up period with no symptoms, and there had been no other complications. Rolla et al. (2004) described a new technique of arthroscopically assisted Bosworth procedure. This technique consists of a closed reduction and stabilization of AC joint with a 7 mm cannulated screw positioned between coracoid process and clavicle. Nine patients were treated with this technique, and after a minimum 5-month follow-up period, all patients had a complete functional recovery, and no residual pain was seen (Rolla et al. 2004). Major difference from the classic Bosworth technique is that the patient and surgical team are not exposed to ionizing radiation. Obligatory screw removal and increased hardware failure have caused this technique not to be widely used.

Chernchujit et al. (2006) reported the arthroscopic stabilization of AC joint using suture anchors with fiberwire tied over a small titanium plate. Twelve out of thirteen patients showed a satisfactory result, whereas three had mild complaints (two had pain, one had loss of motion). Recurrent subluxation of AC joint was seen in two patients, and one patient had complete redislocation. No patient had post-traumatic arthritis. Lafosse et al. (2005) described the arthroscopic Weaver-Dunn procedure for treatment of acute and chronic AC joint dislocations. The acromial branch of the thoracoacromial artery on the coracoacromial ligament was preserved and transferred to the torn CC ligaments. Shorter healing period was expected due to the protection of the vascular structures. The major function of the coracoacromial ligament is to prevent the anterosuperior migration of the humeral head. Therefore, the authors warned that this technique should not be used in patients with an anterior or massive rotator cuff lesion (Lafosse et al. 2005). Snow and Funk (2006) reported their preliminary results of 12 patients operated arthroscopically using the Weaver-Dunn technique. They found promising results with a mean 3-month follow-up. Postoperatively ten patients' AC joints were anatomically reduced, and two patients had residual subluxation. However in these procedures, the strength of the transferred ligament can be only 25% of the normal, and the horizontal stability of the AC joint cannot be achieved, which can lead to recurrent subluxations up to 30% (Harris et al. 2000; Lee et al. 2003; Weaver and Dunn 1972; Weinstein et al. 1995).

The use of allograft or autograft for the anatomic reconstruction of AC and CC ligaments which was initially described by Jones et al. (2001) is a popular treatment method of AC joint injuries. Biomechanical studies have demonstrated that use of a free tendon graft in ligament reconstruction more closely mimics the normal functional anatomy and provides more stronger and stable constructs (Mazzocca et al.

2006; Michlitsch et al. 2010). Over time, this method has begun to be applied arthroscopically. In 2006, Baumgarten et al. defined a new arthroscopically assisted technique by using subacromial approach to pass the semitendinosus allograft or autograft around the coracoid to reconstruct the CC ligaments. Yoo et al. (2010) reconstructed CC ligaments of 13 patients with arthroscopically assisted double-bundle, three-tunnel method using a semitendinosus tendon. Excellent functional and subjective results with high-satisfaction rates were reported in all cases, although an incomplete reduction was observed in two patients postoperatively and mild displacement was observed in three patients who had postoperative anatomic reduction. A new arthroscopically assisted technique was described by DeBerardino et al. (2010). AC Graft-Rope system (Arthrex, Naples, FL/USA) was used in this technique. The Graft-Rope system consists of four strands of nonabsorbable sutures passing between clavicular washer and the coracoid button. The system was designed to accept allograft or autograft like anterior tibial tendon, gracilis, or semitendinosus tendon. The system was performed in ten patients with high-grade AC joint dislocations, and no complication or loss of reduction was observed in early period (DeBerardino et al. 2010). Jensen et al. (2013) have modified this technique by adding transacromial gracilis tendon loop to increase horizontal stability of AC joint in addition to vertical stability provided by Graft-Rope system. The authors suggested using biological substitute with allograft or autograft, especially in chronic cases, as the healing potential of ruptured ligaments is limited in these cases. Pühringer and Agneskirchner (2017) described an arthroscopic technique using a gracilis tendon graft for AC and CC ligament reconstruction in chronic instabilities. They looped the tendon in the figure of 8 around the coracoid, and the risk of fracture was reduced in this way. Also they used a sagittal clavicular tunnel instead of the vertical one. Increase in stabilization and force transmission was intended by using a sagittal tunnel and looping the tendon in figure of 8.

Hook plate has been widely used in AC joint dislocations for many years. Extensive surgical incisions are needed for open reduction of the joint and hook plate placement. And this leads to various complications (soft tissue trauma, blood loss, infection, etc.). Gille et al. (2013) defined a new technique that decreases the risks of open surgery. They performed the hook plate fixation with arthroscopic assistance. The early results of three patients on whom this technique was performed were reported as good to excellent. The authors stated that arthroscopy provides correct positioning of the transacromial drill hole under direct visualization (Gille et al. 2013). As is the case in the classical technique, the necessity of a second operation for implant removal is one of the major problem of this technique.

The use of synthetic CC ligament reconstruction became popular in recent years. Most commonly used synthetic device is the Tight-Rope system (Arthrex, Naples, FL/USA). The system originally has been developed for stabilization of the tibiofibular syndesmosis. Hernegger and Kadletz (2006) first used the Tight-Rope system in the AC joint dislocations and opened the way for its use in such injuries. The system contains two titanium buttons and a no. 5 fiberwire suture (Arthrex) that connects the buttons. The Tight-Rope system is threaded through the 4 mm drill hole in the clavicle and coracoid process using a special guiding device. After the endobutton has been flipped under coracoid, the system is tightened in the proper alignment and secured with 3–4 knots onto the clavicle. In the Tight-Rope system, the CC ligaments are not repaired; system acts as a guide for the healing ligaments. Also the AC and CC ligaments remnants are brought into contact by restoration of the AC joint, and this situation will facilitate healing (Loriaut et al. 2015; Venjakob et al. 2013). Although the system was initially performed with open surgery, the number of the arthroscopic applications increased in the following years.

Hosseini et al. (2009) used Tight-Rope device combined with a coracoacromial ligament transposition in arthroscopic reconstruction of chronic AC joint dislocations. In another study, ten patients treated with Tight-Rope technique for acute AC joint dislocations were evaluated (Gomez Vieira et al. 2015). Authors used UCLA scale as evaluation method and found good and excellent results after an average 15-month follow-up. Four patients had residual pain at the level of AC joint. El Sallakh (2012) reported clinical results of the ten patients with type IV and V AC joint injury treated arthroscopically with the Tight-Rope technique. Author reported one failure of fixation because of technical error, except that no complication was encountered, and all patients were happy with the outcome of the surgery (El Sallakh 2012). Although good clinical and functional outcomes were reported with the use of single Tight-Rope, failure of fixation and loss of reduction have been matters of concern. Defoort and Verborgt (2010) reported 5 residual subluxations in 16 patients treated with single Tight-Rope. Lim et al. (2007), Thiel et al. (2011), and Flinkkila and Ihanainen (2014) reported fixation failure rates 50%, 16.6%, and 16%, respectively. Flinkkila and Ihanainen (2014) argued that the cause of the early and late failures was the suture breakage as the sutures fail easily in cyclic loading. Chaudhary et al. (2015) reported two partial loss of reduction in their series. The authors focus on two views as the reason of loss of reduction. One of the reasons is osteolysis caused by anteroposterior instability of the joint that is not provided by single Tight-Rope, and the other is healing problems of the CC ligaments. If healing does not occur, partial or total loss of reduction may occur (Chaudhary et al. 2015). According to Patzer et al. (2013), the reasons for fixation failure are mainly mechanical. The biomechanics of the CC ligaments cannot be reproduced by only one suspension device, and the fixation is not strong enough to retain the reduction. The frequent recurrences of the postoperative subluxations/dislocations of the AC joint prompted new searches. The importance of the anatomic reconstruction of CC ligaments was elucidated over time, and the use of anatomically placed two Tight-Rope systems became popular.

In their biomechanical study, Walz et al. (2008) compared the cyclic loading and load to failure between anatomic reconstruction with double-bundle Tight-Rope and native CC ligaments in cadaver. The mean vertical and anterior forces measured in static load until failure was significantly greater in the Tight-Rope model. During cyclic loading, the Tight-Rope model had more repetitions until failure than the native ligaments. This study showed that two Tight-Rope systems used in anatomic reconstruction of the CC ligaments led to favorable in vitro results with forces equal to or greater than that of native CC ligaments (Walz et al. 2008). In another study, it is shown that no 5 fiberwire fails biomechanically at 485 N, which for the native CC ligaments is 589 N. So the tensile strength of two strands fiberwire is greater than that of the native CC ligaments (Imhoff and Chernchujit 2004). Ladermann et al. (2013) reported in vitro biomechanical study comparing three techniques used in the treatment of AC joint dislocations. According to this study, double-bundle Tight-Rope reconstruction restricted motion in superior direction more than the native ligaments. As the clavicle was fixed at two points by the two bundle reconstruction, anteroposterior stiffness could also be achieved.

Venjakob et al. (2013) reported satisfactory clinical results with arthroscopic anatomic reduction using two-bundle system after 58-month follow-up. This study included cases that were radiographically over- and undercorrected; however no significant difference was detected in clinical outcomes and patients' satisfaction when compared to patients with normal radiographs. Patzer et al. (2013) described lower coracoclavicular distances in their double Tight-Rope group compared to single Tight-Rope group without significance difference in scores. Scheibel et al. (2011) reported on their 2-year results of 28 patients treated arthroscopically with double Tight-Rope technique. Although partial recurrent anteroposterior and superoinferior instability was present in their study, high satisfaction rates and good clinical results were reported. In another study, favorable clinical results were reported with the use of arthroscopically assisted double Tight-Rope technique. However a posterior instability was detected in 53.3% of the patients on the radiographs (Gerhardt et al. 2013).

Good clinical and functional outcomes were reported in most studies with anatomic reconstruction of CC ligaments using two Tight-Rope systems. However, residual horizontal instability seen in this system can adversely affect the clinical result. This situation has led surgeons to more anatomic reconstructions in recent years. Saier et al. (2015) compared isolated anatomic CC ligaments reconstructions using two Tight-Rope systems to additional AC joint stabilization with suture tape cerclage in their biomechanical study. Significantly increased horizontal stability was found in combined AC joint and CC stabilization group. The authors concluded that physiologic horizontal stability of the AC joint could be achieved by AC and CC reconstructions (Saier et al. 2015). In a clinical study, Barth et al. (2015) found significant correlation between the anatomical outcome and functional outcome. They concluded that no matter which implant is used, only CC stabilization is not sufficient, and anatomic reduction and stabilization in both horizontal and vertical planes are essential to achieve good functional outcome. Tauber et al. (2016) compared triple-bundle (reconstruction of the AC and CC ligaments using autologous semitendinosus tendon graft) and single-bundle reconstructions. Superior clinical and radiological results had been obtained, and horizontal stability had been better restored with arthroscopically assisted anatomic triple-bundle reconstruction. Cutbush and Hirpara (2015) described an all arthroscopic technique in AC and CC ligament reconstruction. They reconstructed the CC ligaments using a single Tight-Rope system, and they used two Healix Advance Knotless anchors (Depuy) making an eight-stranded suture bridge between the clavicle and acromion to reconstruct AC ligaments. The authors' expectation is that this reconstruction technique increases the strength and therefore decreases the failure rate. Braun et al. (2015) reported pearls and pitfalls of their surgical technique they apply to arthroscopically AC and CC stabilization.

De Beer et al. (2017) described a new technique for arthroscopically assisted stabilization of AC joint and reported early clinical and radiographic results of six patients with a mean 7.4-month follow-up. This technique was designed to restore both horizontal and vertical instability. For this purpose, 20 mm open-weave polyester tape (Poly-Tape; Neoligaments, Leeds, UK) and 2 mm ultra-high-weight polyethylene-polyester tape (FiberTape; Arthrex, Naples, Florida) have been used. Stiffness of the repair is provided by the FiberTape and Poly-Tape that acts as a scaffold for fibrous ingrowth and prevents cut out through the bones. Early results of this technique were favorable (De Beer et al. 2017).

8.7.2 Arthroscopic Technique

An arthroscopic coracoclavicular fixation can be achieved with a simple arthroscopic technique without needing any sophisticated surgical instruments, but it should be emphasized that this will only stabilize the vertical instability, for the horizontal instability, acromioclavicular stabilization by using any of the available methods (open oto-allograft fixation of acromioclavicular joint) should be used, though arthroscopic acromioclavicular fixation methods are also evolving.

Our technique to stabilize coracoclavicular instability consists of two steps: First, after posterior portal is opened and scope is inserted into the joint, we open the anterior portal just lateral to coracoid by checking with a spinal needle (Fig. 8.3), then evaluate the shoulder joint in a regular manner, and fix any of the lesions encoun-

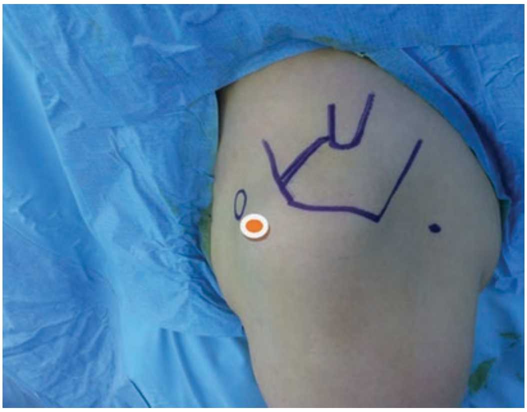

Fig. 8.3 Anterior portal is opened just lateral to coracoid tip

tered (superior labrum, biceps, cartilage, rotator cuff, etc.). Second, while viewing from the posterior portal, we open the joint capsule moderately between subscapularis and biceps tendons (interval) from anterior portal by using RF probe (Fig. 8.4), after this, coracoid is seen 1–1.5 cm superior to the subscapularis tendon's upper edge, and soft tissue of its posterior and inferior surface is cleared off (Fig. 8.5). A 30 degree scope is routinely used, but if the angle of view is not satisfactory, there are two options to get a wider and better view: using a 70 ° scope from posterior viewing portal or opening an extra portal anteriorly (Fig. 8.6), for viewing purpose. After the coracoid is clearly visible posteriorly from tip to base, an ACL (anterior cruciate ligament) guide is placed undersurface of its base and on the clavicle, 3–3.5 cm away from AC joint (Fig. 8.7). A small skin incision parallel to the bone is made and guide pin drilled through the middle of the clavicle to undersurface of coracoid, aiming to center of its base. In this step, viewing from posterior portal is crucial to watch

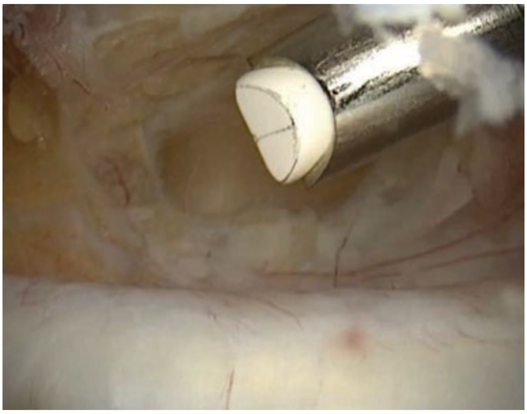

Fig. 8.4 Anterior capsule is opened just above the subscapularis tendon by using RF probe

Fig. 8.5 Soft tissue on the posterior and inferior surface of the coracoid is cleared off

Fig. 8.6 Accessory anterior portal is opened by checking with a needle

Fig. 8.7 An ACL guide is inserted from anterior portal and placed on the clavicle 3–3.5 cm away from AC joint

guide pin exiting undersurface of coracoid. After this step, a cannulated drill is used to over drilling the tunnels to 4.5 mm. Then, an adjustable loop two-button fixation system (there are many on the market) with heavy nonabsorbable four-strand sutures is pushed from the clavicular tunnel until it exits under surface of the coracoid while viewing from the posterior portal. After button exists, it is flipped under coracoid, and sutures are gently tightened by pulling ends coming from the clavicular button (Fig. 8.8). At this step, checking the reduction of AC joint with C-arm is crucial not to under or over-reduce (Fig. 8.9). If the reduction is satisfactory, we then cut the sutures, or only one security knot is tied, because these fixation systems can be locked without knot tying. After the coracoclavicular vertical stability is achieved, then we evaluate the horizontal stability by moving the clavicle in anteroposterior direction. If it is unstable, we add an acromioclavicular fixation by using any of the methods available.

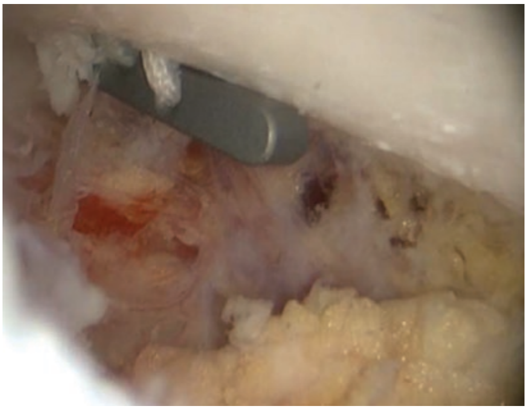

Fig. 8.8 Button is flipped under the coracoid and placed parallel to undersurface

8.8 Complications

Shoulder pain, fractures, loss of reduction, infection, and CC calcification are most commonly documented complications following arthroscopically assisted treatment of AC joint injuries.

Fracture of the coracoid or clavicle is one of the major problems of arthroscopic AC joint reconstructions using bone tunnel drilling techniques. Fractures often occur perioperatively and are caused by technical errors such as incorrect tunnel position or multiple passes of the drill during the implant positioning (Glanzmann et al. 2013; Kany et al. 2012; Martetschlager et al. 2013; Milewski et al. 2012; Scheibel et al. 2011). Coracoid fractures were also reported postoperatively in coracoid loop technique (Tomlinson et al. 2008). Accurate placement of bony tunnels through the center of the bone on a single pass and maximizing the distance between other tunnels and the terminal bone end play a vital role in preventing this complication. Also, the tunnels should not be drilled more than 5 mm in diameter.

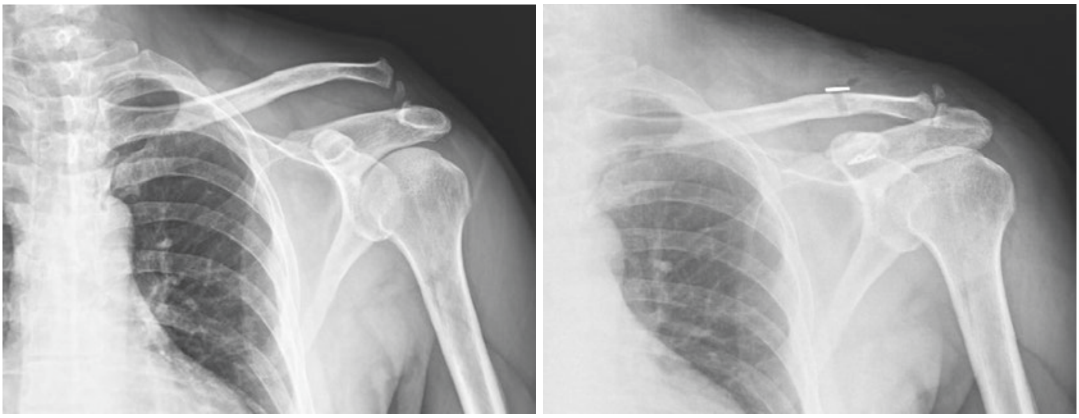

Fig. 8.9 Anatomic reduction is achieved by checking with C-arm

Fig. 8.10 Loss of reduction due to technical error

Loss of reduction is another important complication seen in arthroscopic techniques (Fig. 8.10). High failure rates were observed especially in arthroscopic autograft or allograft ligament reconstruction techniques (Cook et al. 2012; Milewski et al. 2012). Tight-Rope system can be more safer, but this system has a specific complication. Hardware migration into the coracoid, the clavicle, or both was commonly reported with Tight-Rope systems (Scheibel et al. 2011; Vascellari et al. 2015). Hardware migration can be one of the causes of loss of reduction, as well as weakening of the bone and associated stress fractures or fractures after a secondary trauma. For this reason, second-generation TR systems were developed with its round, larger clavicular button that provides better load distribution in the clavicle upper cortex.

Infection rates are lower in arthroscopic techniques than open procedures. Infections reported after arthroscopic procedures were more superficial rather than deep infections (Woodmass et al. 2015). Postoperative shoulder pain can sometimes be an annoying complication and is commonly caused by hardware irritation. Most studies reporting hardware irritation have used the Tight-Rope systems, and the patients usually complained over the superior clavicle fixation site (Cohen et al. 2011; Glanzmann et al. 2013; Salzmann et al. 2010; Scheibel et al. 2011). Clavert et al. (2015) reported this complication up to 46% of cases. Menge et al. (2017) reported an arthroscopic AC joint reconstruction technique using knotless CC fixation device (Knotless AC Tight-Rope device; Arthrex) to overcome this complication. The device is secured by a self-locking mechanism, so there are no knots that cause irritation over the clavicle.

8.9 Conclusion

Recently, many arthroscopically assisted techniques have been described in the treatment of AC joint dislocations. Anatomic reduction and both AC joint and CC stabilization are essential to restore horizontal and vertical instability and achieve good functional outcome. Preliminary results of these studies are encouraging. However, more accurate decisions about the success of these techniques can be made in the following years by obtaining midterm and long-term results.

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9

The Arthroscopy-Assisted Anatomical Reconstruction of Acromioclavicular and Coracoclavicular Ligament in Chronic Acromioclavicular Joint Dislocation

Bancha Chernchujit and Renaldi Prasetia

9.1 Introduction

Acromioclavicular (AC) joint injuries represent 9 to 12% of all shoulder injuries and up to 50% of all sports-related shoulder injuries (Banaszek et al. 2017; Kaplan et al. 2005; Trainer et al. 2008). The mechanism of this injury is typically a direct impact at the acromion in the setting of an adducted shoulder. The initial traumatic force drives the acromion inferiorly, while the clavicle remains in its anatomic position and initiates a cascade of injuries that begins with acromioclavicular ligament failure, followed by failure of the coracoclavicular ligaments. Severe injuries may disrupt the muscular attachments of the deltoid and trapezius from the clavicle as well (Mazzocca et al. 2007). While Rockwood type I–III lesions are commonly treated non-operatively, high-grade injuries (Rockwood IV, V, and VI), as well as many type III injuries in athletes, are considered to be indications for surgery. Additional problems that occur in chronic cases include (1) pre-existing AC joint arthritis, (2) an irreducible AC joint due to soft tissue or scar tissue interposition between or surrounding the acromion process and the clavicle, and (3) suboptimal native structure healing or dependence on nonbiologic materials to maintain reduction.

The principles of AC joint surgical treatment include (1) accurate reduction in the coronal and sagittal planes, (2) repair or reconstruction of the injured ligaments, (3) effective immediate stability to protect repaired or reconstructed tissues, and (4) removal of rigid hardware—if necessary—after ligament healing has taken place to prevent fatigue fracture (Banaszek et al. 2017; Harris et al. 2000; Lee et al. 2003; Lizaur et al. 1994). Different surgical methods have been described that can be categorized as follows: (1) anatomic reproduction of the conoid and trapezoid ligaments, (2) nonanatomic reproduction of a single coracoclavicular ligament without the use of internal fixation hardware, and (3) nonanatomic open reduction internal fixation using hardware (Beitzel et al. 2013; Martetschlager et al. 2016). Treatment of AC joint injuries continues to be controversial among clinicians, with much disagreement on the optimal intervention. Many of these procedures have focused on the coracoclavicular ligaments (conoid and trapezoid) with less focus on the functional contribution of the AC ligaments and the deltotrapezial fascia (Lee and Bedi 2016). In our experience, and according to

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the previous literature, an anatomic repair or reconstruction should address both the coracoclavicular ligaments and the AC ligaments to restore optimal physiologic function (Carofino and Mazzoca 2010; Chernchujit and Parate 2017; Garofalo et al. 2017; Laderman et al. 2011).

Most standard procedures require an open approach with the risk of surgical complications. Visualization of the coracoid in an open fashion involves a large incision, disruption of part of the deltoid insertion, and extensive soft tissue dissection. Even after extensive dissection, visualization medial to the coracoid is limited, and there is a risk to damage to vital neurovascular structures when attempting to pass suture or graft material (Chernchujit and Parate 2017; Chernchujit et al. 2006). Shoulder arthroscopy has evolved, and several arthroscopic techniques have been described for stabilization of AC joint dislocation injuries. Arthroscopic procedures can detect additional intra-articular pathologies associated with AC joint dislocation that might be missed when an open procedure is used. In addition to enabling direct visualization of each surgical step, an arthroscopic procedure can also help minimize the risk of neurovascular injury risk during subcoracoid process procedures (Chernchujit and Parate 2017; Chernchujit et al. 2006; Salzman et al. 2015).

9.2 Surgical Technique

9.2.1 Imaging and Diagnosis

Clinical examination is most important to establish the diagnosis of AC joint dislocation. The AC joint is prone to tenderness with palpation and

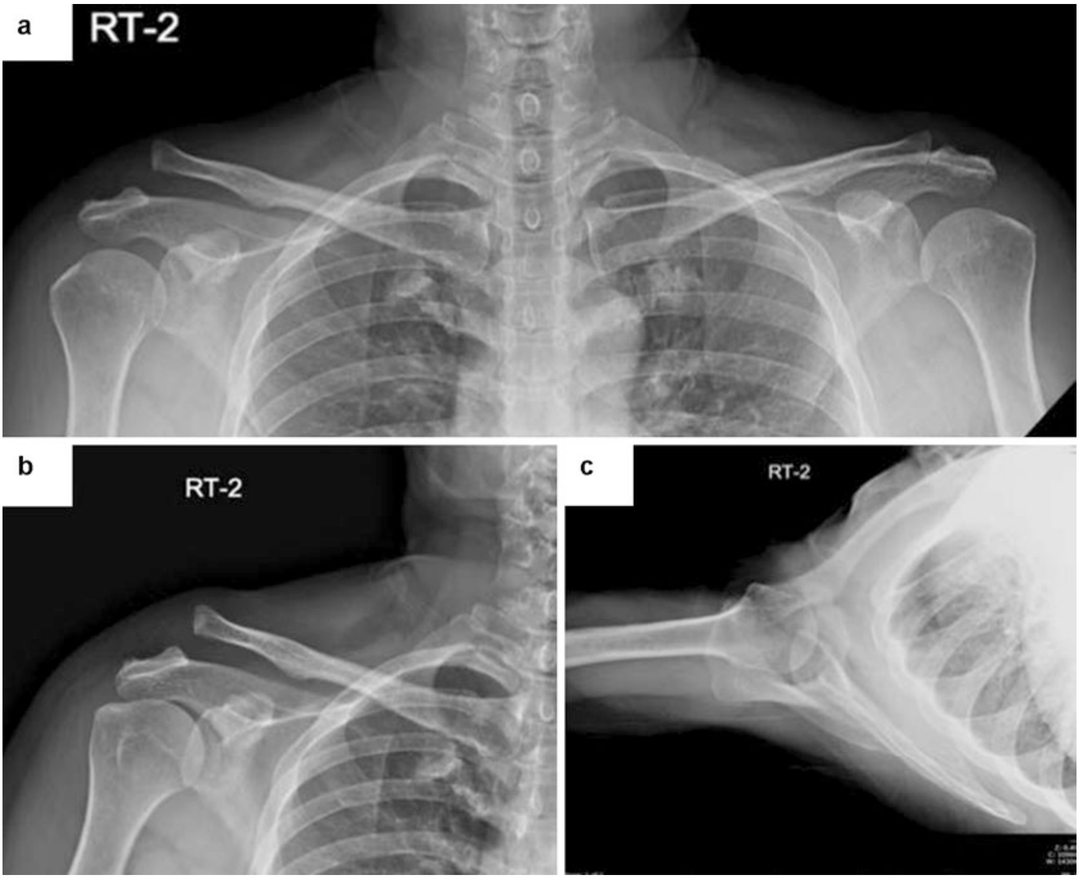

Fig. 9.1 Preoperative radiograph of a patient showing AC joint dislocation

reducibility; however, this must be checked clinically. Radiographs of both shoulders in standing position are an important diagnostic tool to classify AC joint injury and plan treatment. The stress view is obtained as the patient holds a 5-kg weight in both hands while in a standing position. This view is compared with a similar radiograph taken without holding a weight, to assist with surgical planning (Chernchujit and Parate 2017) (Fig. 9.1).

9.2.2 Preoperative Set-Up

The beach chair position is used for AC joint reconstruction surgery. The ipsilateral knee is also prepared for hamstring autograft harvest, and a tourniquet is then placed on the proximal thigh. C-arm preparation and positioning are necessary to make it easier to confirm intraoperative AC joint reduction integrity.

9.2.3 Graft Harvesting: Preparation

A 2-cm transverse skin incision is created over the pes anserinus. The soft tissue is dissected to the level of the sartorius fascia. The upper part of the fascia is identified, and a reverse L-fashioned release is performed subperiosteally. The gracilis and semitendinosus tendons are visualized and bluntly dissected with a right-angle clamp. These tendons are then released from their proximal tibia insertions and whipstitched using a #2 Ethibond suture. Blunt dissection is used to identify and release any adhesions around each tendon. The tendons are then released from the distal muscle-tendon junctions using a tendon stripper.

Following harvest, remnant muscle tissue is debrided from the tendon graft. Pre-tensioning is applied on a traction device with clamps. The proximal ends of the graft are then whipstitched with another #2 Ethibond suture. The purpose for stitching both graft end limbs is to reduce graft diameter as much as possible to better facilitate passage through small bone tunnels. Prior to use, graft length and diameter are evaluated. Graft length and diameter are approximately 240–290 mm and 4.5–5.5 mm, respectively.

9.2.4 Portal Placement: Arthroscopy Diagnostic

Kim's portal (placed 2 cm on a line extended from the posterolateral corner of the clavicle towards the posterolateral corner of the acromion process) is used for visualization (Fig. 9.2). Diagnostic arthroscopy is performed to check for any associated pathology, such as a superior labrum anterior-posterior (SLAP) lesion (Fig. 9.3). The anterior portal is made in the rotator interval just inferolateral to the tip of the coracoid process. Soft tissue in the rotator interval is then debrided to enable access from the tip to the base of the coracoid process. Using a 70° arthroscope may provide better visualization of the base of the coracoid process (Fig. 9.4).

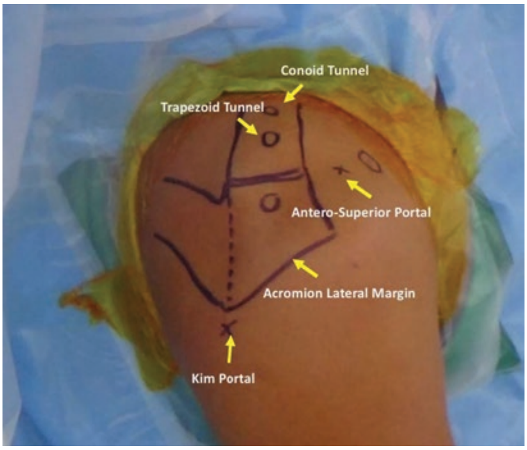

Fig. 9.2 The right shoulder is being operated on, with the patient in the beach chair position. Standard skin markings are done using bony landmarks (tip of coracoid process, anterior and posterior border of clavicle, AC joint, lateral border of acromion process, posterolateral corner of acromion process, and spine of scapula). Kim's portal is a used for arthroscopy and is placed 2 cm on a line extended from the posterolateral corner of the clavicle towards the posterolateral corner of the acromion process

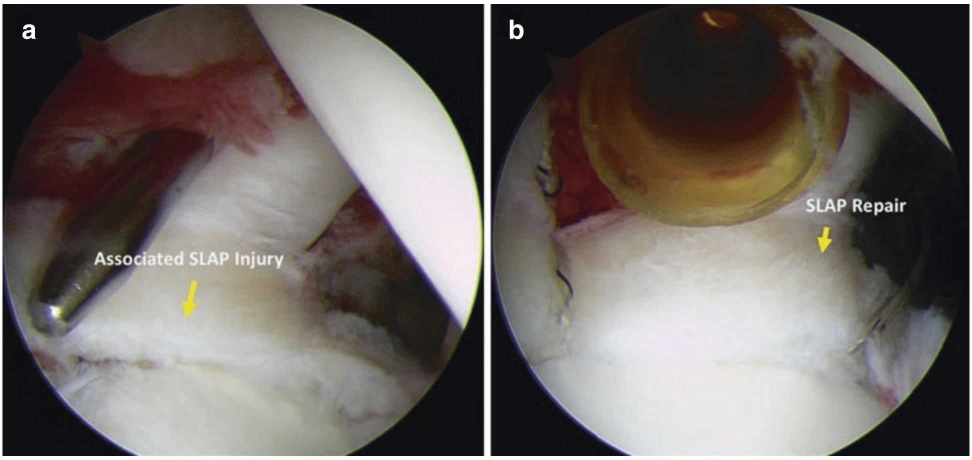

Fig. 9.3 The right shoulder is being operated on, with the patient in the beach chair position. Kim's portal is used for visualization, and a rotator interval portal is made just lateral to the acromion and used for instrumentation. (**a**) A superior labrum anterior-posterior (SLAP) injury as an associated injury of AC joint dislocation was identified. (**b**) SLAP lesion repair

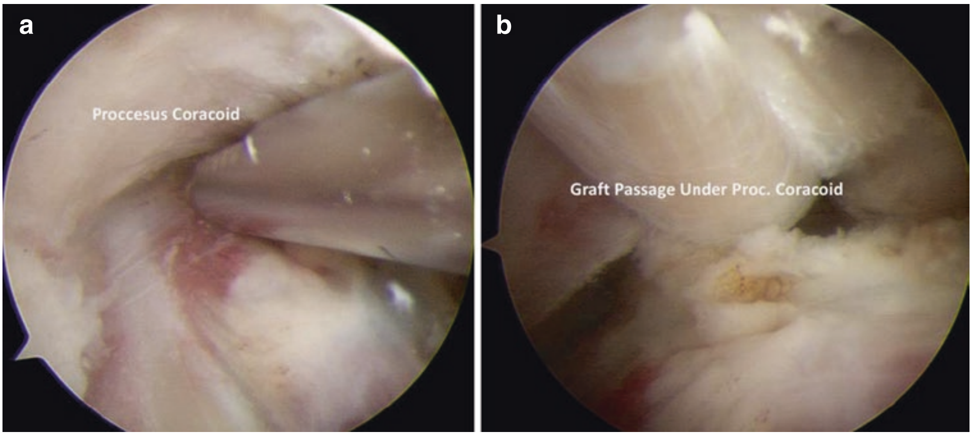

Fig. 9.4 The right shoulder is being operated on, with the patient in the beach chair position. Kim's portal is used for visualization, and a rotator interval portal is made just lateral to the acromion process and used for instrumentation. (**a**) The undersurface of the coracoid process is roughened using a shaver blade, which helps facilitate graft healing. Using a shaver blade ensures the bone is not damaged and the strength of the coracoid process is maintained. (**b**) Visualization of graft passage under the acromion process

9.2.5 Acromioclavicular Joint Preparation

An incision is made approximately 4–5 cm from the anterior border of the clavicle extending laterally 1 cm beyond the AC joint. Skin flaps are raised above the fascia to improve visualization. The deltotrapezial fascia is then elevated off the clavicle as full thickness flaps. The clavicle is exposed. Soft tissue is cleaned from the anterior, lateral, and posterior borders of the clavicle for better mobilization of the clavicle to help in graft passage and AC joint reduction. The exposure is completed by freeing the clavicle and AC joint from any soft tissues that are preventing reduction. In chronic cases, there may be scar tissue inferior to the AC joint. This is incised in parallel with its fibres to gain access to the native joint while also preserving it for later use, if needed, during reconstruction. Distal resection of the lateral 5 mm of clavicle can be performed at this stage using a saw (Fig. 9.5).

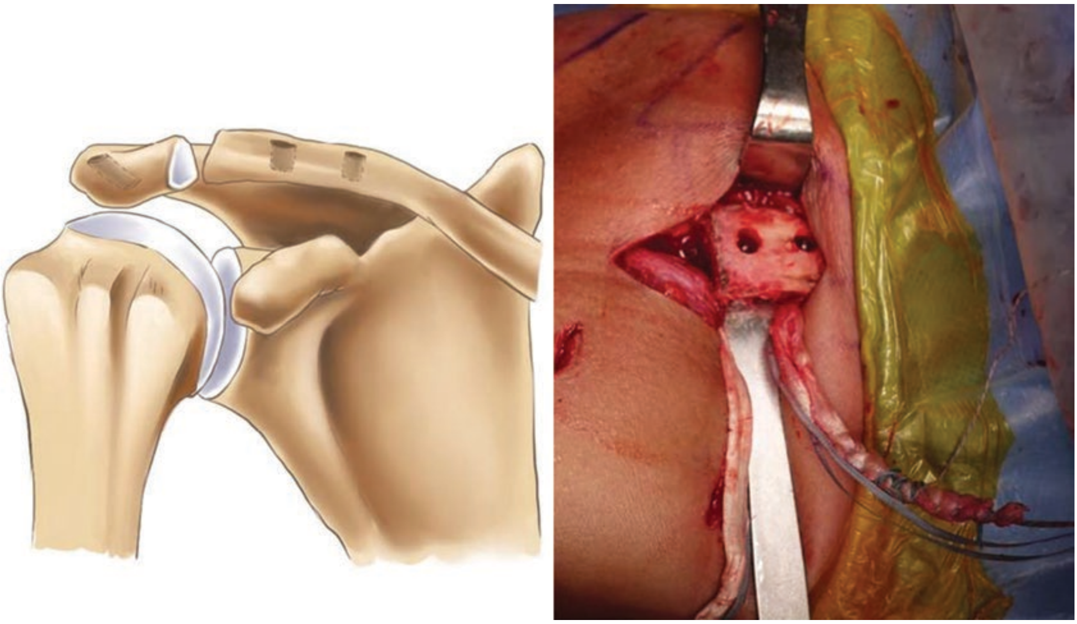

Fig. 9.5 The right shoulder is being operated on, with the patient in the beach chair position. An approximately 4–5-cm incision is made on the superior surface of the clavicle closer to its anterior border. Soft tissues are debrided from the posterior, lateral, and anterior border of clavicle. This helps in AC joint reduction and does not cause any graft passage obstruction. Then, conoid-trapezoid-acromion tunnels are created using individualized tunnel locations

9.2.6 Reduction: Temporary Fixation

Visual inspection is usually adequate for assessing reduction; however, a mini C-arm is used intraoperatively to confirm reduction integrity. A trial reduction is performed by pushing up on the elbow to elevate the scapulohumeral complex and pushing down the clavicle using a blunt and wide-ended device like a tunnel dilator positioned medial to the lateral end holes. When successful AC joint reduction is achieved, temporary fixation is performed using a Kirschner (K) wire.

9.2.7 Coracoid Process Preparation: Graft Sling Passage

The bony undersurface of the coracoid process is exposed, and a roughened surface is created with an arthroscopic shaver to facilitate graft healing. A #5 Ethibond suture is then passed under the coracoid process from the medial side close to the bone. Care should be taken to avoid injury to the nerves that are located medial to the coracoid process. The arthroscope is then inserted once again, and using a hemostat, the suture is retrieved lateral to the coracoid process under direct visualization. A suture loop is thus placed under the coracoid process. A gauze piece is shuttled using the Ethibond suture to verify sufficient space for graft passage. Then, the semitendinosus-gracilis autograft is pulled under the coracoid process.

9.2.8 Acromion-Clavicle Bone Tunnel Preparation

Both limbs of the graft are held vertically parallel to each other, and two points are marked on the clavicle, which will be approximately at the same distance as the width of the coracoid process base. This more individualized approach is preferable, as a fixed distance may not consistently restore anatomy, since bone dimensions differ with each patient (Chernchujit and Parate 2017) (Fig. 9.3). Two tunnels in the clavicle and one in the acromion process are then drilled at a diameter that matches the graft diameter. The undersurface of the acromion process and clavicle are then debrided to enable smooth graft passage. A curved banana shape spectrum device is used to pass a polydioxanone (PDS) suture, and the Ethibond suture loop is passed through the tunnels.

9.2.9 Graft Passage: Fixation

Using a #2 PDS suture as a shuttle relay, the graft is crossed, and the medial end is pulled through the lateral tunnel and vice versa (Fig. 9.6). The graft, passing the most medial tunnel (conoid tunnel), is kept long to enable reconstruction of the superior part of AC joint. The length of graft, passing the most lateral tunnel (trapezoid tunnel), is adjusted to provide adequate coverage for posterior AC joint reconstruction. An Ultrabraid #5 suture and Endobutton are used to provide fixation augmentation and to avoid tissue cut-through (Fig. 9.7). The Endobutton should be firmly positioned on the clavicle using forceps during knot tying so that it stays flush on the bone, maintaining reduction. At this point, the temporary K-wire fixation can be removed.

An Ethibond loop in the acromial tunnel is used to shuttle the graft into the acromial tunnel. The longer end is then passed under the acromion, and it comes out superiorly over the acromion process. In addition to serving as reconstructed ligaments, the interposed graft also serves as an interpositional spacer, replacing the function of the AC joint disc. When the graft is tightened, this pulls and maintains the lateral end of the clavicle in an over-reduced position. The graft is again tied on itself using a #1 Vicryl suture. This procedure reconstructs the coracoclavicular and AC ligaments and provides AC joint reduction. The shorter limb end of the graft is placed at the posterior AC joint and is tied on itself to reconstruct the posterior AC joint capsule (Fig. 9.8).

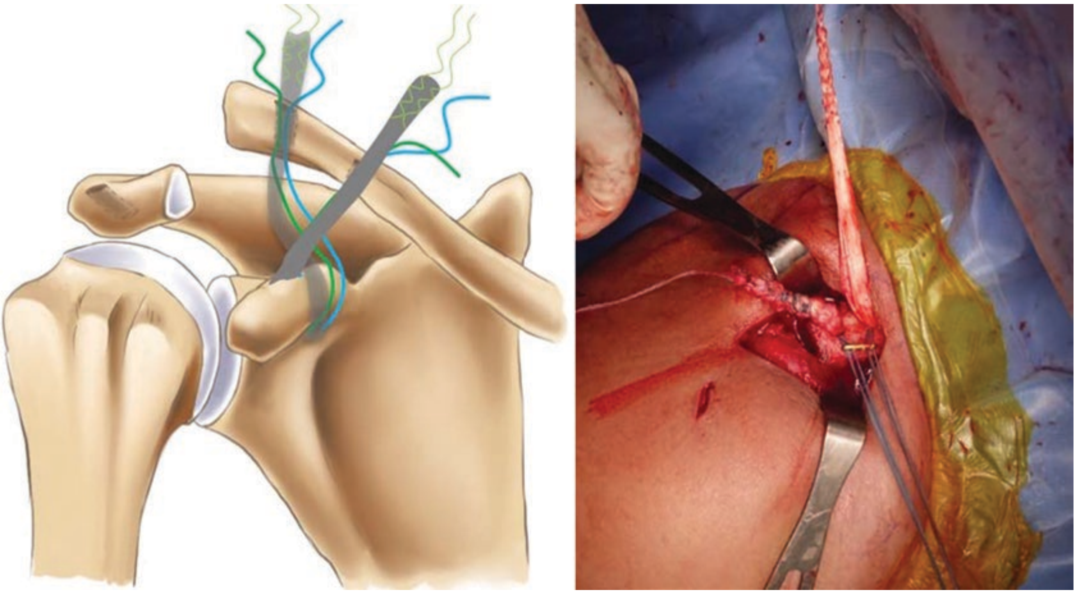

Fig. 9.6 The right shoulder is being operated on, with the patient in the beach chair position. Kim's portal is used for visualization. The grafts with two strong Ultrabraid sutures are shuttled with a gauze piece to create adequate graft passage clearance. The graft is pulled out in such a way that the stronger end of the graft is longer than the other end, which can be used to reconstruct the AC joint

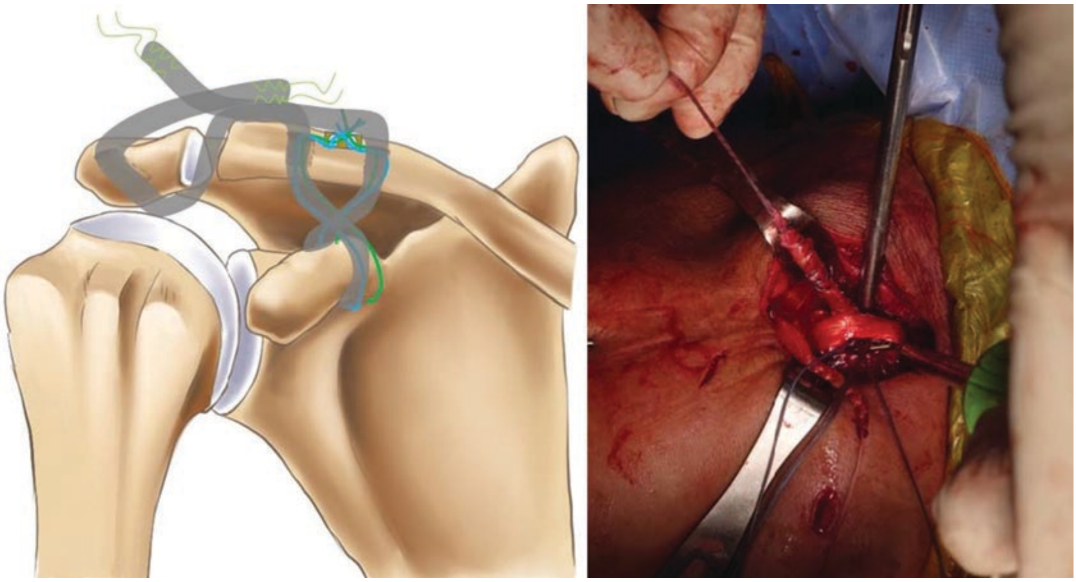

Fig. 9.7 The right shoulder is being operated on, with the patient in the beach chair position. An Ethibond suture loop is passed in the acromial tunnel. It can be done using a wire passer spectrum device for shuttling sutures. The graft is pulled so it goes from the upper surface of the clavicle to the undersurface of the acromion process and through the bone tunnel; it comes out on the superior surface of the acromion process. This helps in further pulling the clavicle downwards, and soft tissue comes between the two bones and mimics an articular disc (anatomic interpositional spacer)

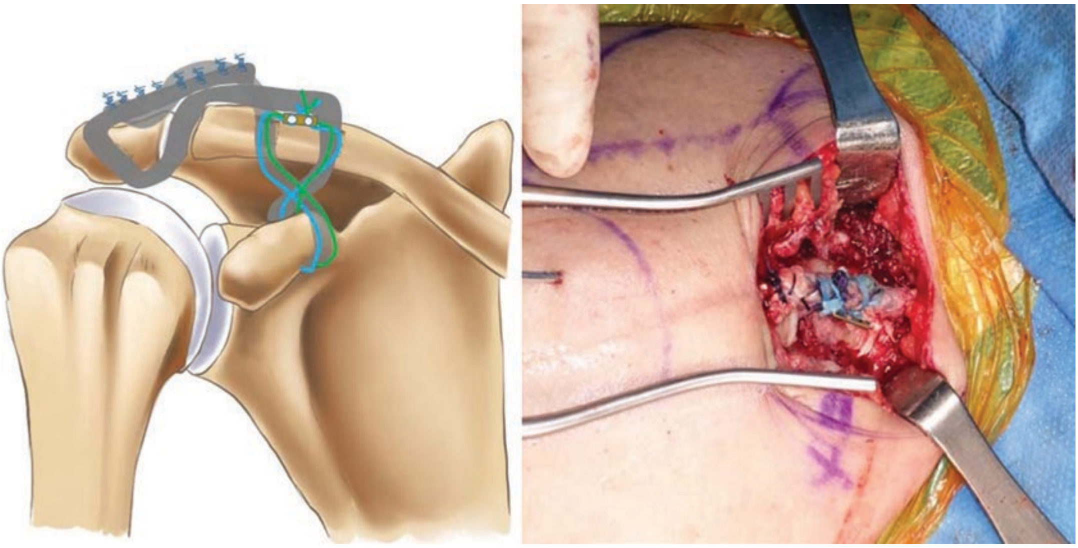

Fig. 9.8 The left shoulder is being operated on, with the patient in the beach chair position. After both graft end limbs were tied to create square knot, the graft is stitched upon itself using Vicryl suture, creating a strong cord on the clavicle

9.2.10 Closure

The deltotrapezial fascia is closed with interrupted non-absorbable sutures. This is a critical step, and great care must be used. Both attachments of the anterior deltoid fascia and the trapezius fascia are brought together with interrupted stitches. The knots are placed on the posterior side of the flap to minimize skin irritation. Occasionally, simple sutures are used to bury knots that appear prominent. The deep dermal layer is closed with buried #3 Vicryl sutures, and an interrupted or running subcuticular closure is used on the skin.

9.3 Post-Operative Care

The arm of the operated shoulder is immobilized in a sling with an abduction pillow for 6 weeks. No shoulder motion is allowed for 3 weeks. Supine passive motion in the scapular plane is initiated at 3 weeks (forward flexion to 90°, full external rotation, and no internal rotation). Active motion begins at week 7. Resistance exercises begin at week 12. Return to full activity including contact sports are allowed at week 16 (Fig. 9.9).

9.4 The Procedure Rationale

The AC ligaments, the coracoclavicular ligaments (trapezoid and conoid), and to some degree the coracoacromial ligament are the primary static AC joint stabilizers. Effective anatomic restoration is the key to the surgical and functional outcome success of various AC joint reconstruction or repair surgeries (Banaszek et al. 2017; Harris et al. 2000; Lee et al. 2003; Lizaur et al. 1994). There are different techniques described for acute as well as chronic AC

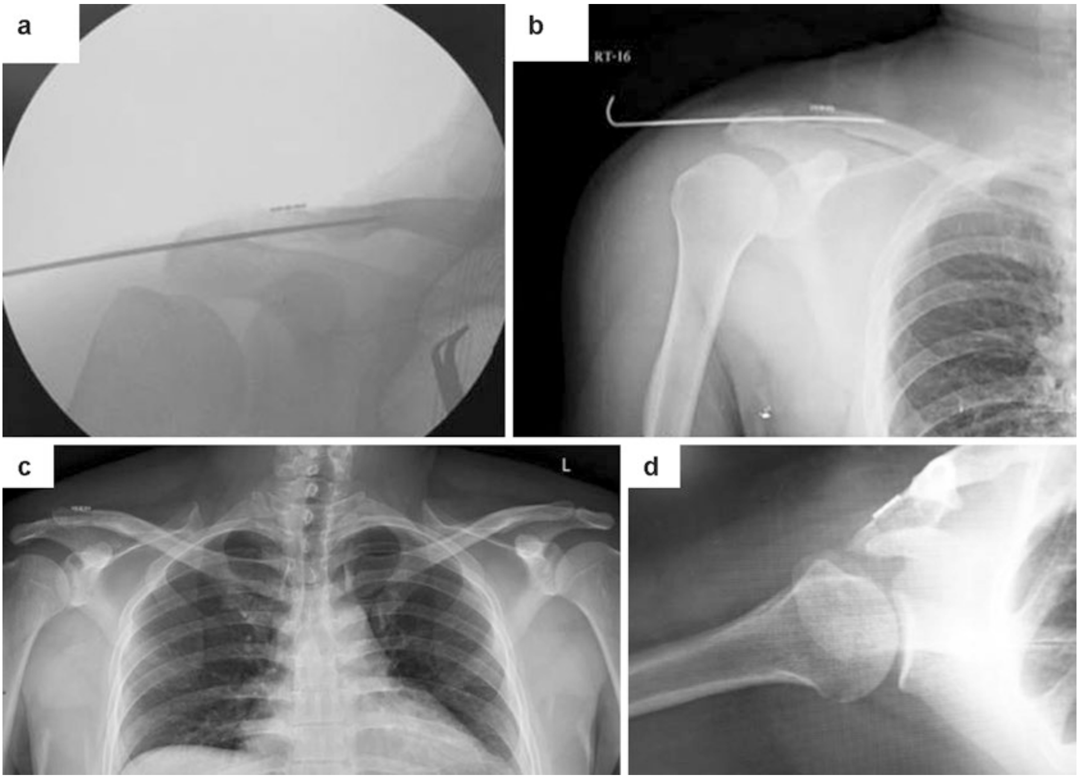

Fig. 9.9 (**a**) Intraoperative C-arm view. (**b**) Immediate post-operative anteroposterior radiographic view of the patient showing AC joint reduction-fixation. (**c**) Six months post-surgery bilateral shoulder anteroposterior X-ray view. (**d**) Six months post-surgery right axillary view radiograph

joint dislocation. Until now, none of the techniques have emerged as the gold standard for AC joint restoration. AC joint separation recurrence rates after surgical reconstruction can range between 20 and 30% or even higher (Scheibel et al. 2008). Persistent horizontal instability in 41% cases following isolated coracoclavicular “double ligament” stabilization repair has been described (Martetschlager et al. 2016; Scheibel et al. 2008).

An arthroscopy-assisted surgical technique to treat AC joint dislocations allows for excellent and safe visualization of the coracoid process to reconstruct the coracoclavicular ligaments with a free tendon graft while at the same time limiting the potential complications associated with traditional open procedures. Arthroscopic procedures can also detect any intra-articular pathology associated with AC joint dislocation that may be missed in an open procedure and treat those simultaneously. Additionally, this procedure can be performed with limited compromise of musculotendinous structures, less morbidity, shorter rehabilitation, and quicker return to activity (Chernchujit and Parate 2017; Chernchujit et al. 2006; Salzman et al. 2015).

The described procedure attempts to anatomically reconstruct the conoid, trapezoid, and AC ligaments using an autogenous hamstring graft. Mazzocca et al. (2006) described reconstructing the conoid and trapezoid ligaments using a free tendon graft, resulting in a construct that displayed almost equal time zero biomechanical conditions compared with the native joint. Saier et al. (2015) reported that combined AC and coracoclavicular ligament reconstruction restored physiological horizontal AC joint stability. The graft was passed from the superior surface of the clavicle to the inferior surface of the acromion, and then it was pulled out of the superior surface of the acromion process. When tightened, the direction of pull on the graft helped to maintain the clavicle in a reduced position (the vector force pushing the distal end of the clavicle downward). Then, both graft limb ends were tied together to cover the superior-posterior AC joint surface, with augmentation provided by a continuous ultra-high-molecular-weight polyethylene (UHMWPE) suture. Soft tissue graft fixation using square knots and graft-to-graft stitching provide equivalent or better biomechanical fixation strength compared to interference screw fixation. Naziri et al. (2016) reported that the added fixation material provided by a UHMWPE suture augmented tendon graft for both AC and coracoclavicular ligament reconstruction increased time zero load to failure strength by 356%.

In chronic AC joint dislocation, we performed 5-mm distal clavicle resection. Biomechanical studies have revealed that a 5-mm distal clavicular resection does not increase clavicular instability or horizontal translation (Boileau et al. 2010). These findings support our choice to resect 5 mm of the distal clavicle. This also allows graft interposition to mimic articular disc function (Chernchujit and Parate 2017). The combination of distal clavicle resection soft tissue interposition and superior-posterior AC joint reconstruction helps to eliminate AC joint pain and improve stability simultaneously.

Two #5 Ultrabraid sutures were used for additional fixation. Use of an Endobutton serves as a cortical augmentation device and spreads fixation pressure over a larger area, thereby reducing the likelihood of fixation loss due to tissue cut-through. In providing this cortical fixation, the sutures were tied first with the clavicle placed in an over-reduced position to insure anatomic reduction at completion. During this procedure, the Endobutton is firmly pressed onto the clavicle, while the sutures are tightened and tied (Chernchujit and Parate 2017). This nonbiologic fixation provides effective immediate AC joint stability providing time for fixation from biological tissue healing to contribute in a more progressive, time-dependent manner.

9.5 Conclusion

An arthroscopy-assisted technique to anatomically reconstruct chronic AC joint injury helps avoid the morbidity associated with open surgery and better promotes anatomical biologic fixation to maintain vertical-horizontal AC joint stability.

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Distal Clavicle Fractures

10

Gernot Seppel and Andreas B. Imhoff

10.1 Introduction

Clavicle fractures are a frequent injury with an incidence of 29–64 per 100,000 persons (Nordqvist and Petersson, 1994; Postacchini et al. 2002; Robinson 1998). In adults they represent 2–5% of all fractures (Neer 1968; Nordqvist et al. 1993; Postacchini et al. 2002).

A particularly high incidence is seen in patients under the age of 30 and over 70 years (Stanley and Norris 1988). Sixty percent of the fractures affect the medial part of the clavicle (Van Der Meijden et al. 2013). In contrast, distal clavicle fractures are relatively rare with an involvement of approximately 15–25% (Edwards et al. 1992; Schliemann et al. 2013; Van Der Meijden et al. 2013).

The most common injury mechanism is a direct trauma to the shoulder or a fall on the outstretched arm (Koppe and Reilmann 2010; Meda et al. 2006). In high-energy trauma concomitant lesions of the scapula and the chest have to be excluded.

The most challenging aspect in the management of distal clavicle fractures is the identification of unstable conditions and associated glenohumeral pathology. In unstable distal clavicle fractures, a disruption of the coracoclavicular (CC) ligaments leads to a displacement of the medial fragment. While stable fracture patterns can be treated nonsurgically, unstable situations should be addressed surgically due to the risk of nonunion (Herrmann et al. 2009; Hessman et al. 1996; Kalamaras et al. 2008; Neer 1963; Neer 1968; Nourissat et al. 2007; Robinson 1998). In addition therapy-relevant intra-articular glenohumeral pathologies like superior labral tears from anterior to posterior (SLAP), partial articular supraspinatus tendon avulsion (PASTA), or pulley lesions occur along with displaced distal clavicle fractures in 25–29% of the patients and should be addressed surgically as well (Beirer et al. 2017; Schwarting et al. 2016).

To understand the complexity of these injuries, it is important to be aware of the anatomy and the biomechanical principles. The clavicle is an important site of insertion for several muscles that are closely involved in the movement of the shoulder and the cervical spine. In addition, it is a crucial pillar between the shoulder joint and the trunk. A stable scapulothoracic motion is maintained by the acromioclavicular joint capsule as well as the acromioclavicular (AC) and

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coracoclavicular (CC) ligaments (Banerjee et al. 2011). While the AC ligaments act as a horizontal stabilizer of the AC joint (Fukuda et al. 1986), the CC ligaments (trapezoid laterally and conoid medially) represent the key structure in distal clavicle fractures and prevent cranialization and displacement of the clavicle. In case of injury, muscular balance may be shifted.

The most common classification system of distal clavicle fractures was established by Neer (1968) and subsequently revised (Craig 2006; Neer 1984) (Figs. 10.1, 10.2, 10.3, 10.4, 10.5, and 10.6).

Fractures that are located lateral to the coracoclavicular ligaments make up the majority of lateral clavicle fractures and are classified as type I according to Neer (Fig. 10.1). They are associated with only slight displacement of the fracture due to soft tissue attachments. Fractures located lateral to the CC ligaments with involvement of the AC joint are graded as type III (Fig. 10.4). These lesions may lead to AC joint arthrosis or osteolysis, requiring surgical treatment at a later stage (Neer 1984). Type I and III fractures sustain anatomic alignment due to intact CC ligaments and can be treated nonsurgically. Type II fractures are challenging as they are considered to be unstable (Neer 1968) (Figs. 10.2 and 10.3). Disruption of the CC ligaments leads to detachment of the proximal fragment, whereas the distal fragment remains connected to the scapula. In type IIA, the fracture is located medially to the conoid ligament. Type IIB is characterized by a fracture running between the trapezoid and conoid ligaments with disruption of the conoid ligament. Due to nonunion rates of 22–33% (Edwards et al. 1992;

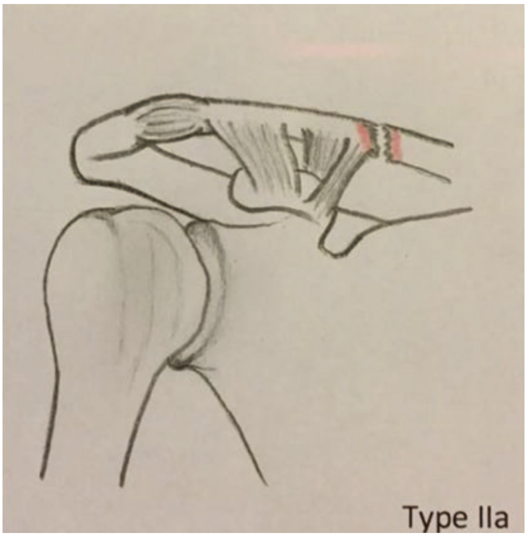

Fig. 10.2 Type IIA: Unstable fracture located medially to the CC ligaments

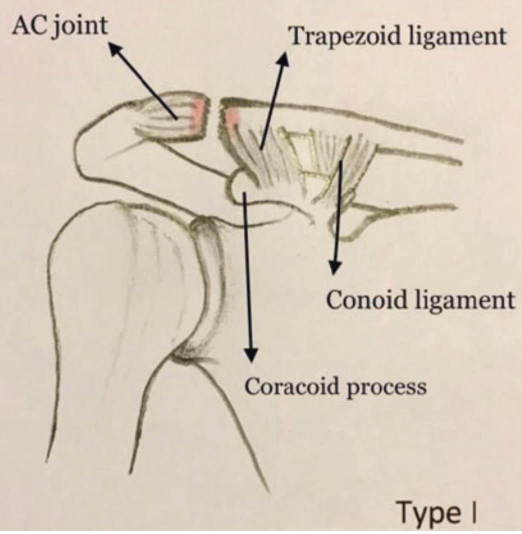

Fig. 10.1 Type I: Fracture laterally to the CC ligaments with slight dislocation and intact AC joint

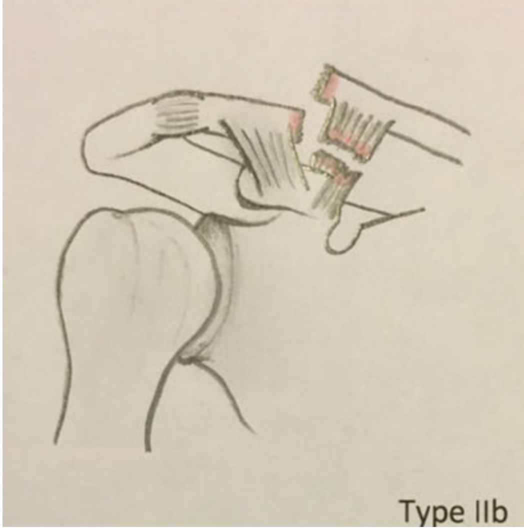

Fig. 10.3 Type IIB: Interligamentary fracture with rupture of the conoid ligament

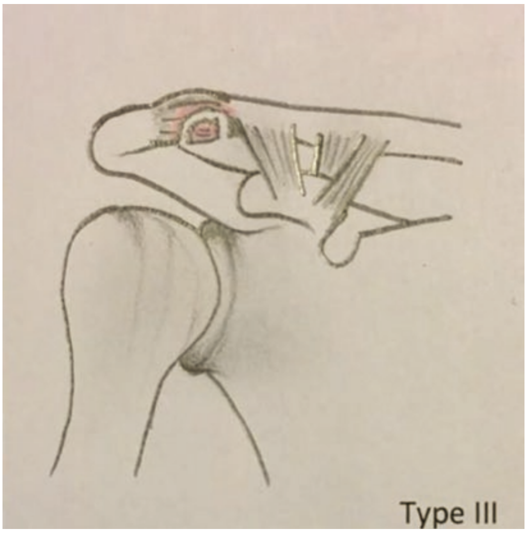

Fig. 10.4 Type III: Fracture laterally to the CC ligaments with involvement of the AC joint

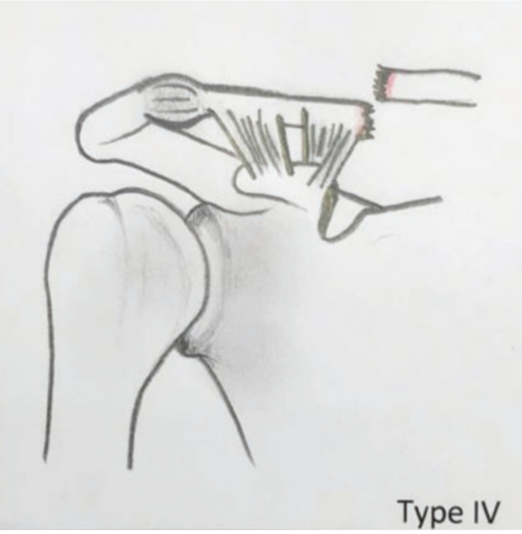

Fig. 10.5 Type IV: Displacement of the clavicular metaphysis in pediatric patients

Eskola et al. 1986; Neer 1968) in these fractures, primary surgical reconstruction is generally recommended (Badhe et al. 2007; Edwards et al. 1992; Flinkkila et al. 2002; Flinkkila et al. 2006; Kalamaras et al. 2008; Kashii et al. 2006; Neer 1968; Nourissat et al. 2007; Robinson et al. 2010). Type IV represents a displacement of the clavicular metaphysis with periosteal disruption (Fig. 10.5). This type occurs in pediatric patients and is commonly treated with closed or open reduction (Ogden 1984). In terms of type V fracture, Craig (2006) added another unstable fracture to the classification (Fig. 10.6). A small inferior, free-floating clavicular fragment remains attached to the CC ligaments without connection to neither proximal nor distal fragment.

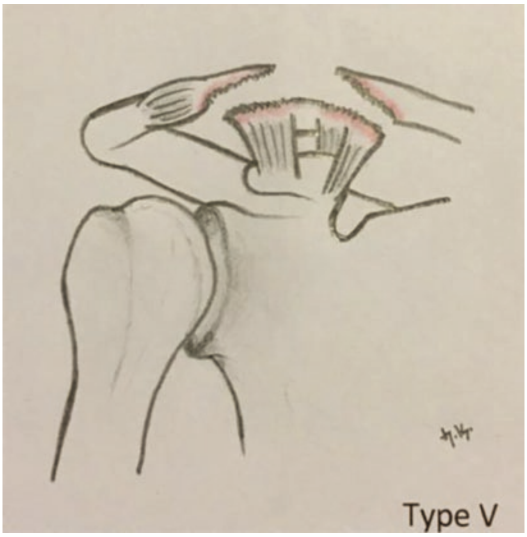

Fig. 10.6 Type V: Displacement of the fractures medially and laterally to the CC ligaments; a small inferior, free-floating clavicular fragment remains attached to the CC ligaments

10.2 Diagnosis

10.2.1 Clinical Examination

Patients with distal clavicle fractures usually complain about shoulder pain and reduced painful range of motion following direct trauma to the shoulder or a fall on the outstretched arm (Koppe and Reilmann 2010; Meda et al. 2006). In addition soft tissue swelling and tenderness over the distal clavicle is present. In case of fracture displacement, elevation of the clavicle—as in AC joint lesions—can be apparent. Concomitant lesions of the cervical spine, the scapula, the ribs, and the thorax as well as neurovascular injuries have to be excluded (Barbier et al. 1997; Chen and Liu 2000; Penn 1964).

10.2.2 Radiological Imaging

To access detailed information in terms of fracture pattern and displacement of distal clavicle fractures standardized radiographic images are recommended. Besides anterior-posterior and axillary images, Zanca and panorama stress views are useful to visualize concomitant lesions, especially of the AC joint (Neer 1963; Robinson et al. 2010; Zanca 1971). Concomitant rotator cuff or labral lesions can be detected by MRI scan.

10.3 Treatment Modalities

Distal clavicle fractures type I and III—commonly non-displaced—are considered to be treated well nonoperatively. In contrast, unstable and displaced type II fractures remain a challenging problem in terms of "gold standard" surgical therapy.

10.3.1 Nonsurgical Treatment

Most of the fractures are non-displaced and can be treated nonsurgically. Nonsurgical treatment of type I and III fractures usually include immobilization with rest in an arm sling, not more than 10 days. After 10 days physical therapy should be started (Khan et al. 2009). Radiographic control is necessary to evaluate bony healing and possible displacement. Usually these fractures heal and recover well. However, distal clavicle resection due to AC arthrosis is often needed (Neer 1968).

10.3.2 Surgical Treatment

Indications for surgical treatment of distal clavicle fractures include open fractures, unstable fractures, and fractures with concomitant neurovascular lesions or involvement of the AC joint especially in young and highly active patients. Fractures in the area of the CC ligaments do not have a stable link to the coracoid process (Neer 1968). Therefore these types of fractures are reported with a high risk of nonunion; this risk has been reported between 28 and 44% following nonsurgical treatment (Deafenbaugh et al. 1990; Neer 1963; Neer 1968; Nordqvist et al. 1993; Robinson and Cairns 2004; Robinson et al. 2004). One study even reported delayed or nonunion rates of up to 75% (Edwards et al. 1992). Generally a high grade of displacement, advanced age, and multiple fragments are known as predictive risk factors for nonunion (Robinson et al. 2004). Twenty to 34% of nonunions are described to be symptomatic and are accompanied with pain and reduced range of motion (Nordqvist et al. 1993; Robinson and Cairns 2004), while some authors do not report significant functional restriction in patients with distal clavicle nonunions (Deafenbaugh et al. 1990).

There is a variety of surgical treatment options including rigid systems like conventional plates, locking compression plates, hook plates, transacromial K-wire, or coracoclavicular screw fixation as well as flexible or combined systems like tension band suturing or arthroscopic-assisted stabilizations (Badhe et al. 2007; Baumgarten 2008; Jou et al. 2011; Kalamaras et al. 2008; Kao et al. 2001; Kashii et al. 2006; Macheras et al. 2005; Martetschlager et al. 2013; Meda et al. 2006; Neer 1963; Nourissat et al. 2007; Pujol et al. 2008; Seppel et al. 2014; Yang et al. 2011; Zanca 1971). K-wire fixation as once recommended by Neer (1963) is reported to have complication rates of 26–31% including infections, nonunion, or migration into the soft tissue (Eskola et al. 1986; Kona et al. 1990; Tsai et al. 2009). Another disadvantage is the implant-associated reduced range of motion during rehabilitation.

Hook plate fixation represents another surgical option to treat unstable distal clavicle fractures especially in cases involving very small distal fragments. Although good clinical results are reported following hook plate fixation, several disorders like subacromial impingement, osteolysis, or fracture of the acromion as well as rotator cuff lesions have to be taken into consideration (Chiang et al. 2010; Tiren et al. 2012). Moreover, a secondary removal of the plate is always mandatory. Accordingly, several surgeons do not recommend hook plate fixation as first-line treatment option in distal clavicle fractures (Stegeman et al. 2013). Moderate to good results are also described following screw fixation (Ballmer and Gerber 1991; Macheras et al. 2005) with union rates of 95% (Fazal et al. 2007). Nevertheless recurring complications of this rigid system like screw loosening or breakage as well as limited range of motion are reported (Ballmer and Gerber 1991; Kona et al. 1990).

Generally, the main problem of many techniques described in the literature is the use of rigid implants, which could lead to loosening, implant failure, nonunion, or subacromial impingement problems of over 20% (Carofino and Mazzocca 2010; Flinkkila et al. 2002; Kashii et al. 2006; Klein et al. 2010; Schliemann et al. 2013). During recent years combined surgical procedures including rigid and flexible devices have been increasingly used, and good clinical and radiological results without substantial problems linked to the implants are presented (Herrmann et al. 2009; Kalamaras et al. 2008; Largo et al. 2011; Martetschlager et al. 2013; Schliemann et al. 2013).

Combinations of locking plates with CC fixation are reported to produce less pain and provide better functional results especially during the first 6–12 weeks after surgery and with lower complication rates (Hohmann et al. 2012; Martetschlager et al. 2013; Stegeman et al. 2013). One study reported that all 30 patients displayed evidence of fracture healing within the first 10 weeks following use of a locking T-plate and an additional PDS cerclage (Martetschlager et al. 2013). They described good clinical function with an average Constant score of 92.3 points at a median follow-up period of 12.2 months. These combined procedures restore vertical and horizontal stability due to the connection of the lateral fragment with the AC joint (Madsen et al. 2013).

The use of arthroscopic minimally invasive procedures in the treatment of distal clavicle fractures has gained a growing importance during recent years. Thus, concomitant glenohumeral lesions (SLAP, pulley, or rotator cuff lesions) that are reported to occur in 25–28.6% of the patients indicate a good possibility to address these injuries simultaneously (Beirer et al. 2017; Schwarting et al. 2016). Moreover, good clinical results with Constant scores over 90 points are described following arthroscopic-assisted fixation using suture-button devices (Motta et al. 2014; Schwarting et al. 2016).

10.4 Author's Preferred Surgical Management

Our preferred surgical technique in unstable distal clavicle fractures is an arthroscopic-assisted combined procedure with a low-profile locking plate (Acumed, Hillsboro, USA) and button/suture augmentation cerclage (DogBone/FibreTape—Arthrex, Naples, USA). This procedure ensures both optimal fracture reduction and dynamic vertical stabilization.

Initially the lateral part of the clavicle is exposed by a 4 cm skin incision. After reduction of the fracture, stabilization is performed by a low-profile locking distal clavicle plate. By using a specific guided aiming device, a Kirschner wire (K-wire) can safely be drilled transclavicularly through the coracoid process under arthroscopic view. Additional vertical stabilization is achieved by shuttling the DogBone/FibreTape—Cerclage from the lateral portal cranially through the clavicular plate arthroscopically. The two ends of the FibreTape cerclage are brought cranially via adjacent holes of the locking plate, while the DogBone button is placed under the coracoid process. Thus a plate bridging can be achieved. Finally reduction is performed, and the cerclage is secured by surgical knotting (Seppel et al. 2014). At the same time concomitant intra-articular lesions can be addressed (Fig. 10.7a–c).

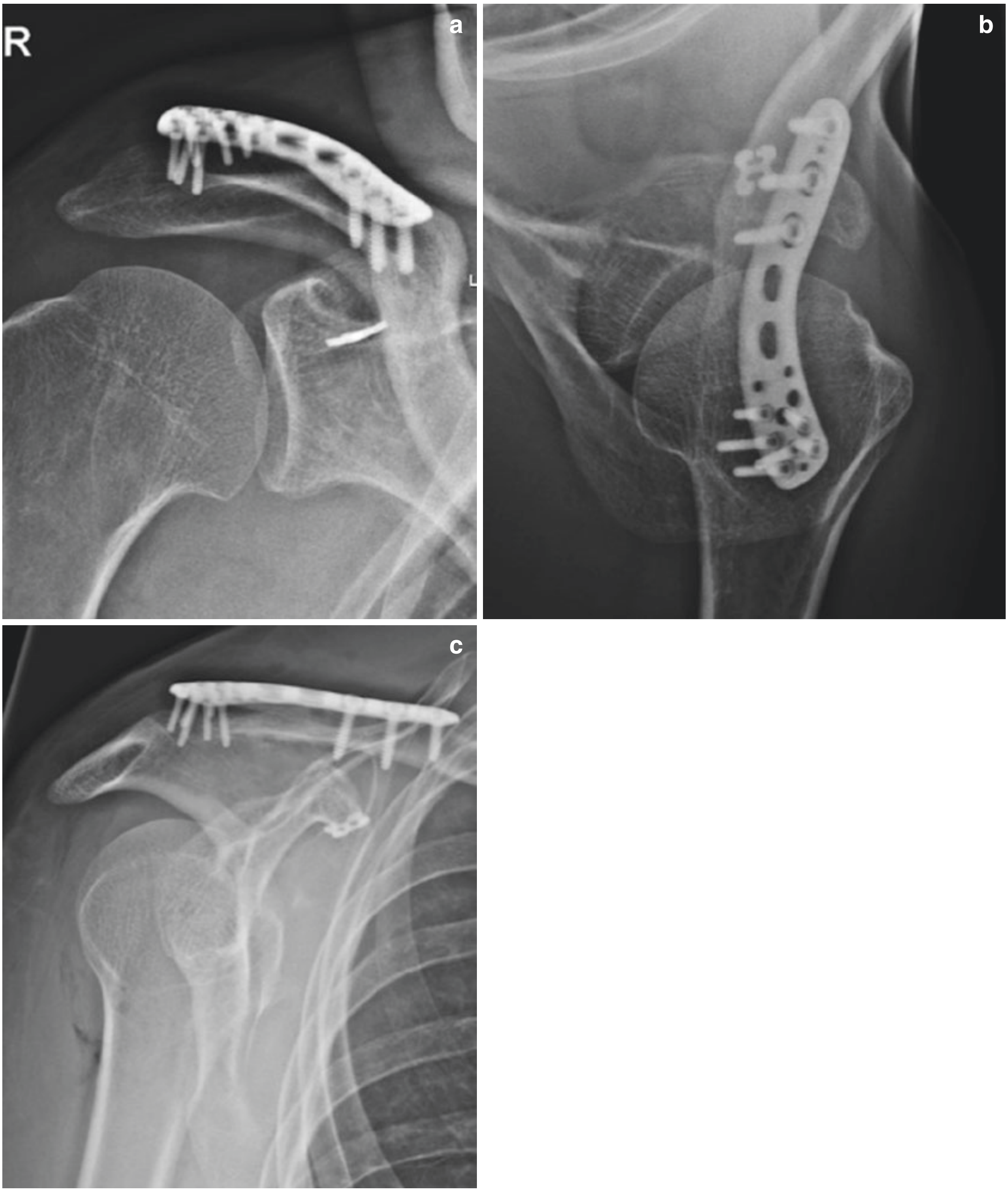

Fig. 10.7 Postoperative X-ray; (**a**) anterior-posterior view, (**b**) axial view, (**c**) Y view

10.5 Postoperative Treatment

Postoperatively, the shoulder is placed in an arm sling for 6 weeks. From the first postoperative day, physical therapy with passive motion to 30° of abduction and elevation as well as to 80° of internal rotation (no external rotation!) is allowed. During the third and fourth weeks, range of motion can be increased actively-assisted to 45° of abduction and elevation, while internal rotation is maintained. At the fifth postoperative week, elevation and abduction can actively be enhanced to 60°, while internal and external rotation is released. After 6 weeks radiographic control is recommended. With good healing progress strengthening exercises can be started.

10.6 Conclusion

Distal clavicle fractures with intact CC ligaments can be treated nonsurgically, while combined osseous and ligamentous lesions (Neer type IIA/B and type V or high grade of displacement) are rated as unstable with high rates of nonunion. Accordingly, unstable fractures should be managed surgically with arthroscopic-assisted combined procedures of rigid plate fixation to ensure optimum fracture reduction (low-profile locking plate) and dynamic vertical stabilization (CC augmentation). To date no single technique has proven to be the "Gold Standard" procedure.

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11

Glenoid Fractures

Ladislav Kovacic and Pascal Gleyze

11.1 Introduction

Scientific data for glenoid fracture management are mostly limited to case reports and case series of heterogeneous patient populations. This is the reason why there is a lack of widely accepted optimal treatment strategies. Avulsion fractures and glenoid rim fractures are associated with anterior shoulder dislocations and may cause shoulder instability. Glenoid fossa fractures are the result of direct impact of the humeral head against the glenoid and are mostly seen in high-energy trauma. To avoid chronic instability or degenerative joint changes, surgical treatment consisting of anatomical reduction and internal fixation is recommended in significantly displaced fractures. Over the last two decades, arthroscopic glenoid fracture fixation techniques have been increasingly described and patient outcomes reported. Minimally invasive techniques are replacing open procedures, especially in bony Bankart lesions that involve less than 25% of the glenoid surface. Arthroscopic treatment of these injuries using suture anchors is safe and reliable. Arthroscopic treatment of large fragment(s), anterior glenoid rim fractures using percutaneous screw fixation provides stable osteosynthesis during healing and improves glenohumeral joint stability. Soft tissue management is important to preserve blood supply and reduce the risk of restricted motion, which often occurs following open procedures. Nevertheless, many questions still remain, including the indication for operative treatment and decision making to achieve the best clinical result while minimizing surgical risks.

11.2 Glenoid Anatomy

The glenoid articular surface is pear-shaped and slightly concave from superior to inferior and from side to side making a shallow cavity or glenoid fossa. The superior portion is narrow, and the inferior part is wide forming a circle. The vertical diameter (height) of the glenoid cavity is longer than the horizontal diameter (width). Two studies reported on the size of the glenoid (Churchill et al. 2001; Iannotti et al. 1992). The mean height was 36.5 mm (range 29.4–48 mm) and mean width 26.6 mm (range 19.7–35 mm) (Vanderbeck et al. 2009). The variations in glenoid size are different between genders and on the average height of the person (Vanderbeck et al. 2009).

The glenoid surface is orientated in a near perpendicular orientation to the scapula. Interestingly, glenoid orientation is different

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among races, but not between genders (Churchill et al. 2001). The mean reported retroversion is 1.3° (range − 9.5 to +10.5°) (Churchill et al. 2001). Evaluation can be difficult, because the superior part is more anteriorly orientated than the inferior part (Matsen et al. 2009). There is also marked variation in glenoid inclination. Despite wide variation in results, the majority of shoulders display between 0 and 9.8 degrees of inclination (range − 7 to +15.8°) (Churchill et al. 2001).

The glenoid cavity is rounded by a fibrous structure—labrum. The fibers of the labrum are continuous with the hyaline cartilage in infants, but as aging occurs, the labrum assumes a looser position and resembles a knee meniscus with a free intra-articular edge (Vanderbeck et al. 2009). The labrum serves as a static shoulder stabilizer and is the attachment point for the glenohumeral ligaments. The glenoid surface is covered by hyaline cartilage that is thinner in the center and thicker at the edges thus forming the bare spot—the center point of the inferior circular part (Vanderbeck et al. 2009). The articular cartilage adds to glenoid concavity, which is formed by the shape of the bony socket. The labrum at the glenoid periphery deepens the glenoid cavity further.

11.3 Pathomechanics and Fracture Types

Different glenoid fracture types correspond to variations in trauma mechanisms. There should be careful distinctions between the pathomechanics associated with glenoid avulsions, glenoid rim fractures, and glenoid fossa fractures.

Glenoid avulsions are common in patients who have sustained shoulder dislocation. They are observed in injuries following sports trauma or low-energy trauma. Typically, the anteroinferior glenohumeral ligament and its attachment are involved. Glenohumeral ligament avulsion with or without a bony fragment occurs from an indirect force associated with excessive capsulo-labral-ligamentous complex traction caused by humeral head dislocation during forced abduction-external rotation (Van Oostveen et al. 2014). Non-healing of this avulsion is a major factor in recurrent traumatic instability (Matsen et al. 2009).

Fractures of the glenoid rim occur when force applied over the lateral aspect of the proximal humerus strikes the humeral head against the periphery of the glenoid cavity. The result can be a chisel-like fracture that may be as large as 1/3 of the articular surface (Fig. 11.1) (Van Oostveen et al. 2014). Glenoid rim fracture is sometimes

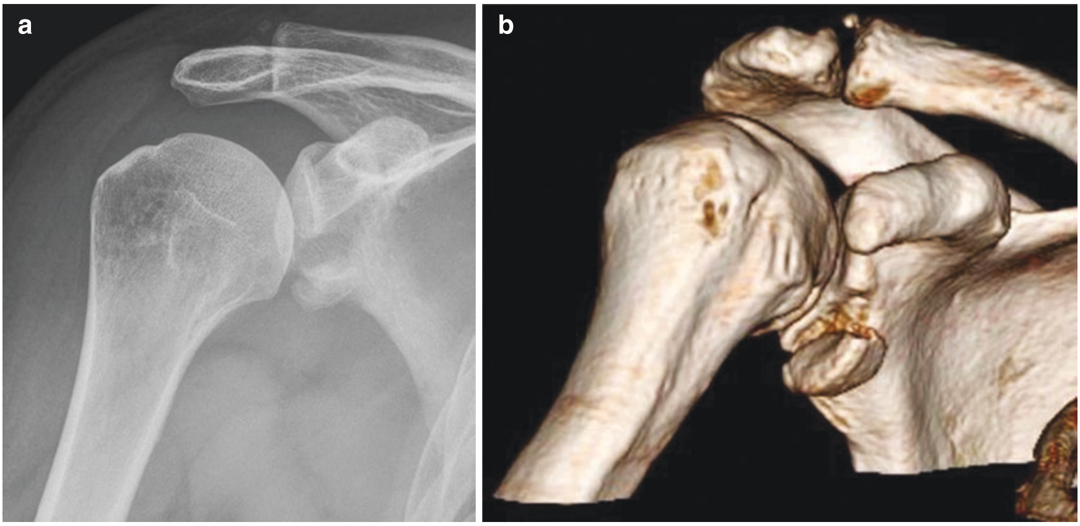

Fig. 11.1 Fracture of the anteroinferior glenoid rim; radiograph (**a**) and CT scan (**b**)

associated with shoulder dislocation or subluxation in sports-related trauma in younger patients or due to traffic accidents in older patients (Maquieira et al. 2007).

Fractures of the glenoid fossa occur when the humeral head is driven with significant force into the center of the glenoid concavity (Goss 1992). The fracture generally starts as a transverse or slightly oblique fracture line in the direction of the applied force. Once a transverse disruption occurs, the fracture can propagate in a variety of directions and extend through the body into the medial border of the scapula (Fig. 11.2). The initially applied force and additional pulling forces result in fracture displacement. The triceps pulling on an inferior fragment results in an inferior displacement. Moreover, the conjoined tendon pulling on a superior fragment including the coracoid results in an anteroinferior displacement (Schandelmaier et al. 2002). The second mechanism for this type of fracture is blunt trauma with direct force causing scapular fracture, which extends into the articular surface (Bahk et al. 2009). Glenoid cavity fractures are mostly associated with high-energy trauma and therefore often associated with concomitant injuries (Armitage et al. 2009). The severity of concomitant injuries may be the reason for delay in diagnosis and treatment.

Fig. 11.2 Fracture of the glenoid fossa; CT scan

Fracture classification. Ideberg (1984) proposed the first detailed scapular fracture classification system, which was further modified by others (Goss 1992; Theivendran et al. 2008). This classification, originally based on radiographs, is the most widely used, and it consists of six main fracture types. Type I fractures involve the glenoid rim, type Ia the anterior rim, and type Ib the posterior rim. Fractures of the glenoid fossa make up types II to V. Type VI injuries include all comminuted fractures with more than two glenoid cavity fragments. The classification has not been shown to be of prognostic value; however, it is useful when planning the surgical approach (Goss 1992; Schandelmaier et al. 2002). For anterior glenoid rim defects, classification based on the work of Bigliani et al. (1998) can be used. Bigliani actually coined the term bony Bankart to indicate the presence of an anteroinferior bone fragment. Bigliani's modified classification includes glenoid rim fractures types I–III (Scheibel et al. 2009). Type I represents an acute lesion with a displaced bone fragment with attached capsule, which is further graded to type Ia, osteochondral avulsion; type Ib, large solitary fragment; or type Ic, multifragmented anterior glenoid rim. Type II represents a chronic, malunited, or nonunited fracture fragment with poorly defined ligamentous structures. Type III is characterized as a chronic lesion without bone fragment and includes type IIIa, erosion of the glenoid with less than 25% glenoid bone loss, and type IIIb, bone loss greater than 25% (Bigliani et al. 1998; Scheibel et al. 2009).

11.4 Epidemiology

Glenoid cavity fractures are rare injuries. They comprise up to 10% of scapula fractures, which represent only 0.4–1% of all fractures (Bahk et al. 2009; Goss 1992; Wiedemann 2004). Additionally, substantially displaced fractures only represent approximately 10% of all glenoid fractures (Goss 1992; Hardegger et al. 1984; Ideberg 1984). Therefore, operative treatment is relatively uncommon.

Anterior glenoid avulsions and glenoid rim fractures are more common than glenoid fossa fractures. They account for 75–85% of all glenoid fractures (Ideberg 1984). There is a wide age range distribution showing average glenoid rim fracture patient age to be between 40 and 50 years, while the majority of glenoid fossa fractures occur in young males (Ideberg et al. 1995). Reports suggest that anterior glenoid rim or avulsion fractures occur in 5–75% of all anterior shoulder dislocations (Goebel and Seebauer 2008; Ideberg et al. 1995). The cause for this large variation in incidence might be different avulsion and rim fracture definitions and the use of different imaging techniques. Posterior glenoid rim fractures are present in 4–11% of patients with an acute posterior shoulder dislocation (Goebel and Seebauer 2008).

11.5 Treatment Indications

The purpose of glenoid fracture treatment is to maintain articular congruity, restore articular stability, and prevent post-traumatic shoulder arthritis. The main parameters, which have to be considered when deciding if operative treatment is indicated, are instability, articular surface fragment size, and degree of displacement (Lantry et al. 2008). Operative treatment is increasingly advocated (Anavian et al. 2012; Kavanagh et al. 1993; Osti et al. 2009; Plath et al. 2015; Porcellini et al. 2002; Raiss et al. 2009; Schandelmaier et al. 2002; Scheibel et al. 2004; Scheibel et al. 2016; Tauber et al. 2008). In a recent review, 80% of glenoid fractures were treated operatively (Zlowodzki et al. 2006). However, there is a lack of clear scientific data in terms of what significant displacement is and which patients will benefit from operative treatment. The reported results are difficult to interpret due to differences in fracture type and surgical approach. Studies report on small patient groups and patient selection is different. Treatment protocols and functional outcome of those patients are often non-standardized. There are also few reports on non-operative treatment of these fractures showing that good results comparable to operative treatment can also be obtained (Jones and Sietsema 2011; Kligman and Roffman 1998; Maquieira et al. 2007). It can be concluded that there are inconsistent practice patterns and the lack of evidence-based criteria guiding glenoid fracture management leading to substantial treatment decision variation. Frequently, surgeon and patient preferences have more influence than guidelines criteria (Mulder et al. 2015).

Nevertheless, some guidelines can be advocated on the basis of scientific reports and some proposed treatment algorithms (Goss 1992; Goss et al. 2009; Ideberg 1984; Van Oostveen et al. 2014). The main parameters defining operative treatment are instability, articular surface fragment size, and to a lesser extent the degree of displacement (Adam 2002; Goss 1992; Osti et al. 2009). Operative treatment is therefore advocated if the humeral head is not centered on the glenoid, if the fragment size exceeds 20–25% of the glenoid surface in anterior fractures, or 33% in posterior glenoid fractures, or if there is more than a 5 mm displacement of the fracture fragment (Table 11.1) (Itoi et al. 2000; Konigshausen et al. 2016; Maquieira et al. 2007). However, additional concomitant injuries and patient personality and requirements should be considered when deciding on operative treatment (Bahk et al. 2009).

Table 11.1 Indications for operative treatment of glenoid fractures

Parameter	Value
Glenohumeral stability	Uncentered humeral head on the glenoid
Fracture fragment size	20–25% of the anterior glenoid surface 33% of the posterior glenoid surface
Fracture fragment displacement	Fracture gap 5 mm or more Fracture step-off 5 mm or more
Additional factors to be considered	Age (less than 30 years) Patients activity level

11.6 Surgical Treatment

Displaced intra-articular fractures of the glenoid have been traditionally treated operatively by open reduction and internal fixation. Screw fixation or even suture anchor repair has been reported with good results (Osti et al. 2009; Raiss et al. 2009; Scheibel et al. 2004). Depending on the fracture type, anterior or posterior approaches have been used (Lewis et al. 2013; Schandelmaier et al. 2002). In case of anterior or superior glenoid fractures, the deltopectoral approach is preferred; therefore, the patient is placed in the beach chair position. In contrast, a posterior approach is used for posterior and inferior glenoid fractures and fractures in combination with fracture of the scapular neck and/or body. For this procedure, the patient is placed in the lateral decubitus position.

Over the last two decades, there has been an evolution in arthroscopically assisted and all arthroscopic surgical techniques for glenoid fracture reduction and fixation (Cameron 1998; Plath et al. 2015; Porcellini et al. 2002; Scheibel et al. 2016; Tauber et al. 2008). Glenoid rim fractures (Ideberg Ia and Ib) are especially manageable using this minimally invasive approach (Bauer et al. 2006; Carro et al. 1999; Frush and Hassan 2010; Sano et al. 2009; Sugaya et al. 2005). Recently, arthroscopically assisted reduction and percutaneous fixation of select multiple fragment glenoid fractures have also been reported (Gigante et al. 2003; Tuman et al. 2015; Yang et al. 2011). Arthroscopic treatment of anterior glenoid rim fractures is a well-described and well-evaluated operative technique. Indications, however, are limited to acute, fresh injuries. As for open operative treatment, it can be performed using suture anchor repair, percutaneous screw fixation, or a combination of techniques.

11.6.1 Arthroscopic Surgical Technique

The patient is placed either in the lateral decubitus or beach chair position. The later allows for easier conversion to an open approach if needed. Arthroscopy is performed using a standard posterior portal. Anteriorly, a standard anterosuperior working portal is established through the rotator interval 1 cm lateral to the coracoid process and after inserting a working cannula. Joint irrigation is then performed, and the fracture hematoma is evacuated. Loose articular debris and small fragments are also removed. Depending on the surgeon's preferred technique, an additional anterolateral or suprabicipital portal can be used as a working or viewing portal. Next, the fracture fragment is mobilized using elevators, rasps, a probe, or a blunt trocar. The labral ring is frequently partially broken on at least one side of the fracture line, but the capsuloligamentous complex together with corresponding labrum is still attached to the fracture fragment. Depending on fragment size and labral complex integrity, screw fixation, suture anchor repair, or a combination of the two is performed. In the case of smaller avulsion fractures or multifragmented glenoid fractures, suture anchors are used. In larger, solid, and solitary fragments, screw fixation is preferred. Combining both implants, the surgical procedure can be performed more easily (Fig. 11.3). In the first step, two suture anchors are sequentially inserted into the glenoid. An anchor is first placed in the glenoid rim just above the superior fracture line. Following this, a second anchor is placed in the glenoid rim just below the fracture fragment. Sutures are then placed on the preserved capsule-labral complex at the superior and inferior margin of the fracture fragment correspondingly similar to the classic arthroscopic Bankart repair. When the suture knots are tied, the osseous fragment is indirectly reduced and temporarily stabilized. However, the osseous fragment is often malaligned in torsion so the second step, screw fixation, provides additional reduction, stability, and fracture line compression. For the second step, an additional anteroinferior portal is needed through the subscapularis tendon. The guide wire is inserted through the anteroinferior portal, and the fragment is provisionally fixed. Confirmation of screw position is then done using fluoroscopy. Depending on the case, the same or the second guiding wire is used to drill the bone and place the cannulated screw

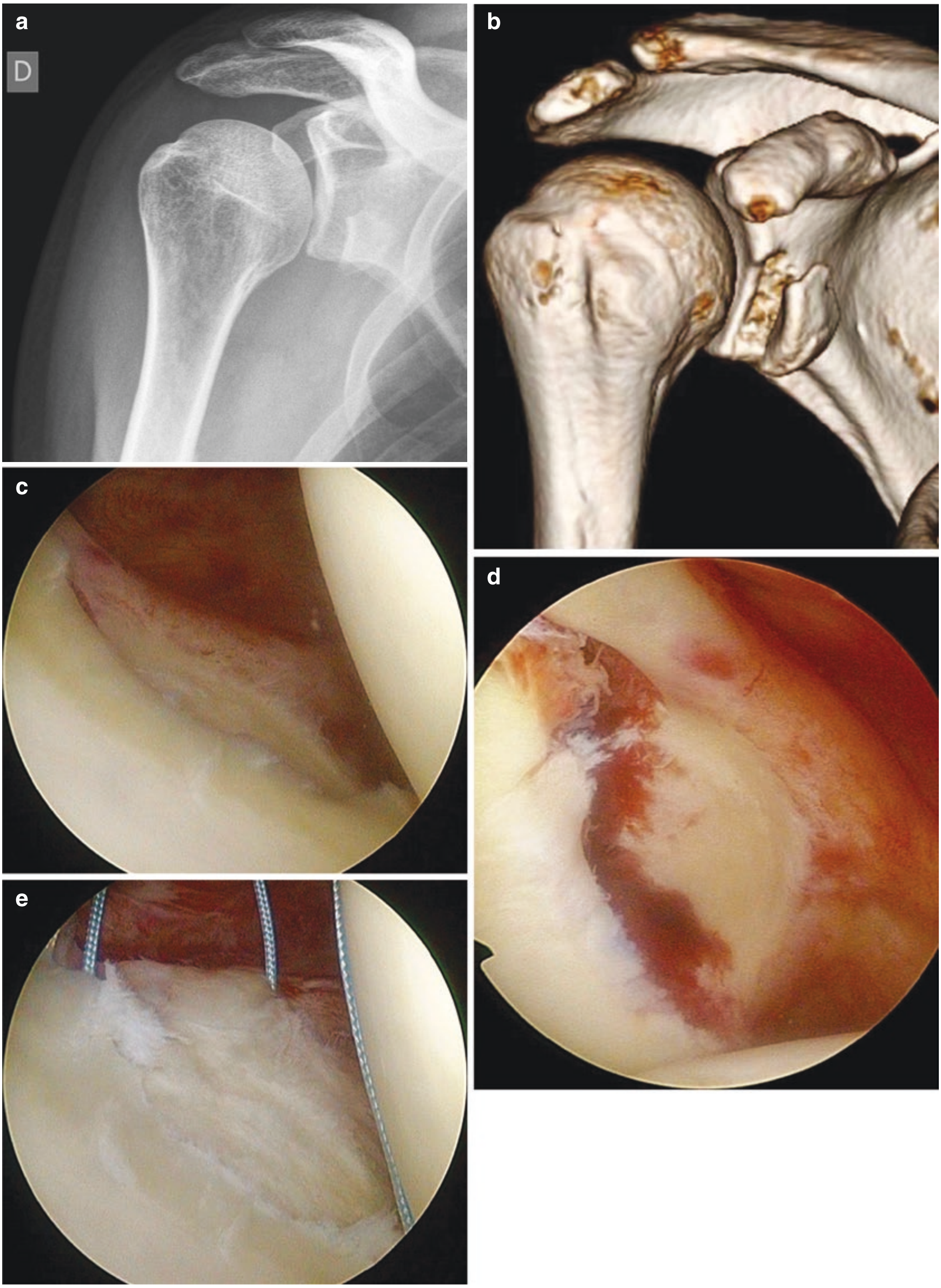

Fig. 11.3 Clinical case of arthroscopic treatment of anterior glenoid rim fracture. Initial radiograph (**a**) and CT scan (**b**). Arthroscopic view of the same fracture from posterior portal (**c**) and anterior portal (**d**). Reduction of the fracture and sutures in place through labro-ligamentous complex superior and inferior to the fracture line (**e**). Sutures tied with fragment reduced to the glenoid surface level (**f**). Final radiograph with additional screw inserted percutaneously to obtain fragment compression (**g**)

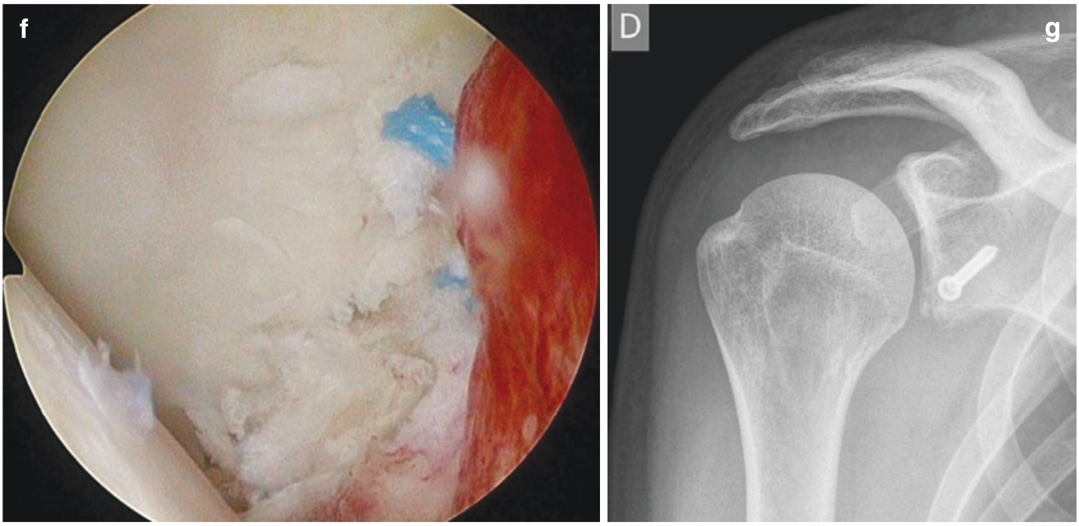

Fig. 11.3 (continued)

across the fracture. Definitive arthroscopic and radiographic observation of effective fracture reduction and fixation is verified prior to guide wire removal. In some cases, additional concomitant injuries can be detected, and treatment is carried out accordingly.

11.7 Results of Treatment, Complications, and Unanswered Questions

The majority of reports on glenoid fracture treatment describe good results for stability, function, and patient satisfaction. However, results between different studies are difficult to compare and interpret due to differences in fracture types, the relatively small number of patients, different patient selection methods, and different treatment options (Table 11.2) (Osti et al. 2009; Plath et al. 2015; Porcellini et al. 2002; Raiss et al. 2009; Schandelmaier et al. 2002; Scheibel et al. 2016; Sugaya et al. 2005; Tauber et al. 2008).

Use of an open approach to displaced glenoid fractures with intra-articular displacement of more than 5 mm has traditionally yielded good results if there are no additional injuries such as brachial plexus palsy and an absence of postoperative complications (Schandelmaier et al. 2002). However, unanswered questions remain about operative glenoid fracture management. Study findings in terms of operative large anterior glenoid rim fracture treatment have similar results as studies that report conservative treatment; however, the latter group represents only a few reports (Konigshausen et al. 2016; Maquieira et al. 2007; Raiss et al. 2009). Even patients with fragment dislocation of more than 3 mm have excellent clinical results and a high subjective satisfaction rate (Maquieira et al. 2007). Conclusions from the literature suggest that nonoperative and operative treatments in concentrically reduced rim fractures, where the humeral head is well-centered on the glenoid, yield similar good results (Raiss et al. 2009). Therefore, the true indications for surgical treatment have to be further studied in the future with well-designed comparative studies.

More than one study has reported that screw impingement may cause pain if the screw is placed too medial to the glenoid rim (Raiss et al. 2009; Tauber et al. 2008). To solve this problem, a minimum distance of 3 mm from the glenoid rim, screw placement underneath the joint line, and smaller implants are recommended (Osti et al. 2009). Additionally, screw impingement and irritation may be a reason for glenohumeral joint osteoarthritis. Recently, bioabsorbable screws developed in accordance with arthroscopic surgical techniques have been proposed to

Table 11.2 Results after open and arthroscopic treatment of glenoid rim fractures according to several authors (CS = constant score)

Study	Patient number	Mean age (years)	Follow-up (years)	Pathology	Treatment option	Functional result	Complications
Schandelmaier et al. (2002)	22	34	10	Displaced glenoid fossa fractures	16 posterior approach, 6 anterior approach	CS 79%	0 redislocations 2 deep infections 2 brachial plexus palsy
Raiss et al. (2009)	29	41.6	6.5	Anterior glenoid rim fractures	Open, screw fixation	CS 93.3%	0 redislocations 8 screw removal 6 osteoarthritis lower strength and endurance
Osti et al. (2009)	20	49.4	3.1	Anterior glenoid rim fractures	Open, screw fixation	CS 90 Rowe 90	0 redislocations 1 implant failure 1 neurological dysfunction 3 osteoarthritis
Porcellini et al. (2002)	25	25.6	Min 2	Avulsion bony Bankart lesion	Arthroscopic, suture anchors		0 redislocations 10 deg. loss of ext. rotation 0 osteoarthritis
Sugaya et al. (2005)	42	22,9	1.4	Chronic anterior glenoid rim fractures	Arthroscopic, suture anchors	Rowe 94.3 UCLA 33.6	2 redislocations
Tauber et al. (2008)	10	38.2	4.75	Anterior glenoid rim fractures	Arthroscopic, screw fixation	Rowe 94	1 redislocations 1 screw removal 0 nonunion (CT) 4 deg. loss of ext. rotation
Plath et al. (2015)	50	41.2	6.8	Avulsion bony Bankart lesion	Arthroscopic, suture anchors	Rowe 85.9	3 redislocations 8 deg. loss of ext. rotation 16.6% nonunion (MRI) 70% chondral lesions (MRI)
Scheibel et al. (2016)	23	47.9	2.7	Anterior glenoid rim fractures	Arthroscopic, screw fixation ± suture anchors	CS 84.5 Rowe 90.8	0 redislocations 0 nonunion 7 osteoarthritis

overcome problems associated with permanent metal materials (Scheibel et al. 2016).

The development of glenohumeral joint osteoarthritis in patients following glenoid fracture is not fully understood. The rate of osteoarthritic changes, which is not negligible, has been described in some studies; however, long-term follow-up is lacking (Osti et al. 2009; Plath et al. 2015; Raiss et al. 2009; Scheibel et al. 2016). Osteoarthritis development rates are comparable in reports of operative treatment preformed with suture anchors, metal screws, or combination of both. Correlation between medial glenoid step-off and osteoarthritic changes has not been confirmed, whereas patient age at the time of the surgery seems to be important (Plath et al. 2015;

Scheibel et al. 2016). Patients with the signs of osteoarthritis are on average 10 years older compared with those that do not experience osteoarthritic changes (Scheibel et al. 2016). Prognostic factors for the development of osteoarthritis have been studied only for patients with glenohumeral instability. It has been shown that patient age at the time of the initial dislocation and at the time of operative intervention and the existence of an osseous lesion are important factors (Seybold et al. 2006). However, for patients with a glenoid fracture, it is not clear whether the development of osteoarthritis is due to the initial trauma and its energy, the injury displacement, the dislocation type, or the type of operative treatment.

Glenoid fracture nonunions or redislocation is rarely described in the literature (Plath et al. 2015; Tauber et al. 2008). While this is a rare event, it is difficult to study and explain its precise contribution to glenohumeral joint stability. It remains unclear whether stability is achieved by fracture reduction and healing or if it is a result of post-traumatic or postoperative scar formation.

It is hypothesized that arthroscopic glenoid fracture treatment may be superior to an open surgical approach because of functional deficits following muscle detachment, especially the subscapularis tendon for anterior glenoid rim fracture repair (Fig. 11.4). To our knowledge, there are no comparative studies in the literature so far. Functional deficits following detachment and later repair with subscapularis muscle and anterior capsule shortening have been studied by Raiss et al. (2009). They reported that open screw fixation of anterior glenoid rim fractures led to excellent functional results in 86% of patients. However, they also found significant differences in the mean external rotation range of motion between the affected and unaffected sides, and 14% of patients had a 15–20% strength deficit in all directions of motion. Interestingly, there were significant external rotator strength deficits (Raiss et al. 2009). In contrast, results of arthroscopic treatment have shown no internal rotation strength impairments and no subscapularis lesions (Tauber et al. 2008).

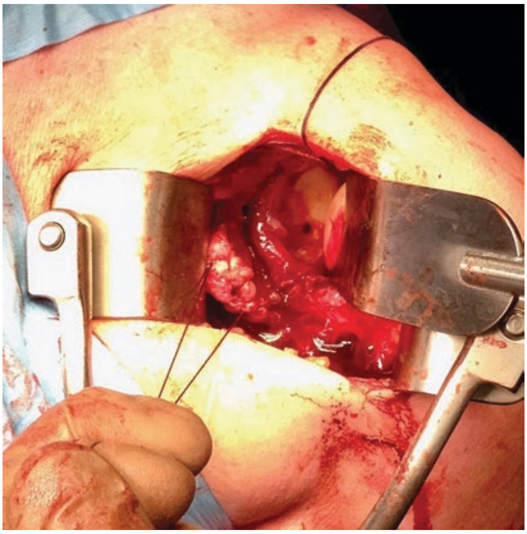

Fig. 11.4 Open approach to glenoid fracture fixation with subscapularis and anterior capsular detachment

Loss of external rotation range of motion, which has been observed in some series, is not completely understood. Itoi et al. (2000) demonstrated that glenoid defect of 1 cm would entail the loss of 25 degrees of external rotation. Therefore, optimal fracture and capsulo-labral complex reduction also helps to limit the loss of external rotation range of motion. Itoi et al. (2000) also found that the proportion of patients experiencing loss of motion treated for glenoid fracture was similar to that reported for the arthroscopic treatment of the classic Bankart lesion.

The safety of minimally invasive glenoid rim fracture treatment using percutaneous screw fixation might be questioned. There are few case reports of neurovascular complications (Schneibel et al. 2016; Seybold et al. 2006; Tauber et al. 2008). Anterior percutaneous approaches are reportedly associated with a greater risk of injury to the cephalic vein, musculocutaneous nerve, and the inferior branch of the suprascapular nerve (Marsland and Ahmed 2011). Superior and posterior percutaneous approaches appear to be safe with minimal risk to the suprascapular vessels and axillary nerve. Fracture orientation needs to be accurately assessed before surgery so that the optimal screw insertion angle can be established.

This is especially important when arthroscopically assisted treatment is used for multiple and more complicated glenoid fracture patterns (Gigante et al. 2003; Gras et al. 2013; Tuman et al. 2015; Yang et al. 2011).

Potential advantages of minimally invasive glenoid fracture treatment include preservation of the muscle and tendon function around the shoulder thus achieving comparable or better functional results over a shorter period of hospitalization and rehabilitation. Additionally, direct visualization using arthroscopic technique allows accurate fracture fragment reduction and fixation. Finally, in addition to decreased morbidity, an arthroscopic technique allows more secure diagnosis and treatment of associated injuries. Continuous development and proper evaluation of arthroscopic techniques and materials for glenoid fracture fixation may lead to improved future clinical outcomes.

11.8 Conclusion

Arthroscopic glenoid fracture treatment including glenoid rim avulsions and large solitary and multifragmented glenoid rim fractures has been frequently reported over the last two decades. More recently, arthroscopically assisted treatment for glenoid fossa fractures has been introduced. The advantage of direct fracture visualization and soft tissue preservation may lead to improved clinical outcomes. Fracture fixation using suture anchors or screw fixation ensures anatomical fracture healing and restoration of glenohumeral joint laxity. Further comparative studies are needed in order to improve the level of scientific evidence supporting different treatment methods. Moreover, since similar results can be obtained in some patients using non-operative treatment alone, the ideal indications still remain to be determined. The radiographic fracture fragment displacement and size threshold for operative treatment should be investigated. Probably, an improved evidence basis may shift more glenoid fracture cases toward arthroscopic operative care.

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12

Arthroscopic Treatment of Greater Tuberosity Fractures of the Proximal Humerus

Eric G. Huish and Uma Srikumaran

12.1 Background

Isolated fractures of the greater tuberosity of the humerus account for a minority of the two-part proximal humerus fractures (Green and Izzi 2003). However, with the greater tuberosity serving as the insertion of the rotator cuff, fractures can have significant functional consequences. Nonoperative treatment of isolated greater tuberosity fractures has been shown to have good outcomes when little (<3 mm) or no displacement is present (Rath et al. 2013). Both Constant and patient satisfaction scores show satisfactory results, but the average time to full recovery was 8 months. Studies that have shown greater tuberosity fragment displacement >3 mm but <5 mm had slightly worse clinical outcomes than those with displacement <3 mm, however not statistically significant (Platzer et al. 2005). While minimally displaced greater tuberosity fractures can be appropriately treated nonsurgically, greater tuberosity displacement has been shown to increase the force required for glenohumeral joint abduction (Bono et al. 2001). This displacement can also cause anatomic impingement, shoulder pain, and impaired shoulder joint motion. Clinical outcomes with displacement >5 mm have also been shown to be inferior (Platzer et al. 1999). While the exact degree of displacement necessitating operative fixation is controversial, there is little controversy that fractures with significant (>10 mm) displacement require fixation. If there is a question in terms of the amount of displacement present, computed tomography or magnetic resonance imaging is recommended (Carrera et al. 2004). Good outcomes for range of motion, patient-reported outcomes, and pain have all been reported after surgical fixation of displaced greater tuberosity fractures (Yin et al. 2012).

12.2 Surgical Technique

Traditionally, open reduction internal fixation of displaced greater tuberosity fractures has been performed. This has involved various fixation methods including screws, plates, and tension bands. However, since its first description in 1994, advances in arthroscopic techniques have led to an increasing popularity of arthroscopic reduction and fixation (Geissler et al. 1994). The small incisions utilized for arthroscopy have an obvious cosmetic benefit. Avoiding the need to retract the deltoid muscle, as is necessary with open procedures, can also help prevent axillary nerve injury. The fracture bed can be debrided and reduced under direct visualization (Fig. 12.1), and the articular surface can be carefully examined.

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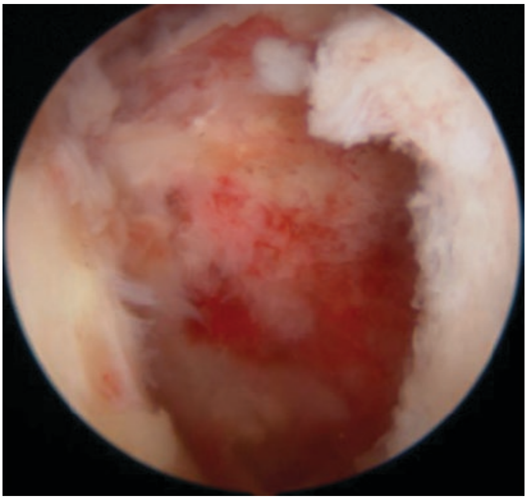

Fig. 12.1 Arthroscopic image of debrided fracture bed during fixation of a greater tuberosity fracture

Arthroscopy also has the advantage of allowing the surgeon to visualize the glenohumeral joint and treat concomitant injuries. Significant soft tissue injuries have been reported to be associated with proximal humerus fractures (Platzer et al. 1999). Partial rotator cuff tears have been seen specifically in greater tuberosity fractures and have been a source of continued pain after fracture healing (Kim and Ha 2000). As greater tuberosity fractures are associated with glenohumeral dislocations, (Green and Izzi Jr. 2003) labral and osteochondral lesions may be present. The ability to increase diagnostic accuracy and treat associated injuries while minimizing damage to surrounding tissues makes arthroscopic fixation techniques attractive.

Various greater tuberosity fixation methods have been reported. Initially, treatment included fixation with partially threaded screws (Taverna et al. 2004). More recently, suture fixation has been used in different configurations (Figs. 12.2a–c and 12.3a–c). Biomechanical data has shown increased load to displacement for various suture configurations compared with screw fixation (Lin et al. 2012). Suture fixation also has the advantage of using the strong bone tendon junction to hold sutures rather than trusting possible osteoporotic bone to hold screws. Suture fixation can also be used in cases with very small or commi-

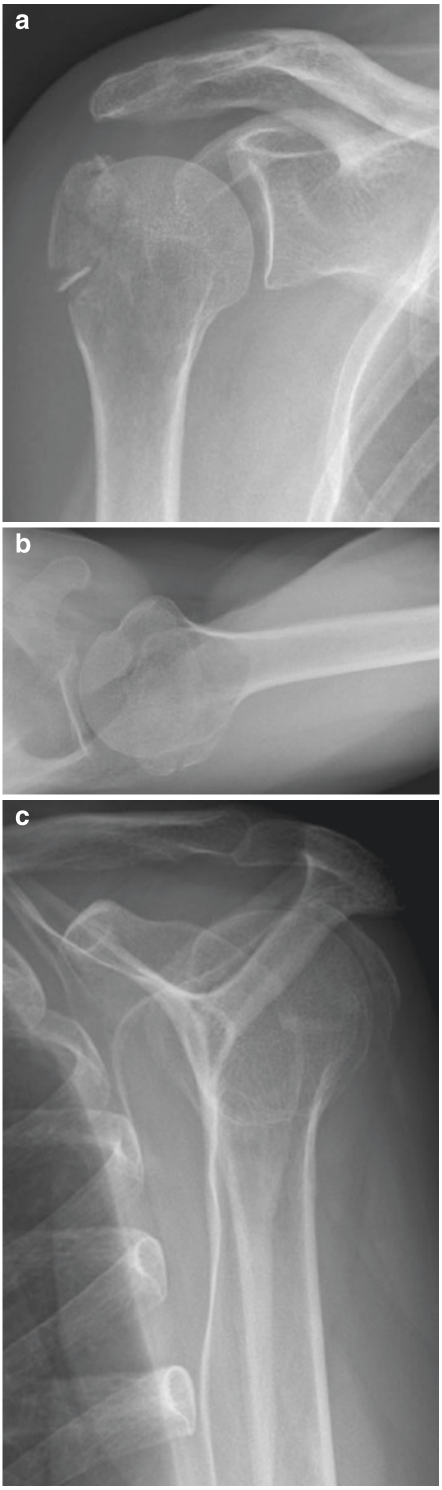

Fig. 12.2 (**a**–**c**) Anterior/posterior, axillary, and scapular Y views of an isolated greater tuberosity fracture with displacement

nuted fractures, where screws may not be the best solution (Ji et al. 2010). Double-row fixation (Ji et al. 2007) (Figs. 12.4 and 12.5) and suture bridge fixation (Kim et al. 2008; Song and Williams Jr. 2008) have both been described. Biomechanically, a suture bridge construct shows higher forces required for displacement of 3 mm but not for 5 mm (Lin et al. 2012). Single-row fixation has also been reported with purported benefits of shorter operative time, technical ease, and less damage to an intact rotator cuff; however, there is little data to support these claims (Lee et al. 2012). As surgeons have become more comfortable with these techniques, arthroscopic fixation of greater tuberosity fracture malunions have been reported as well (Martinez et al. 2010).

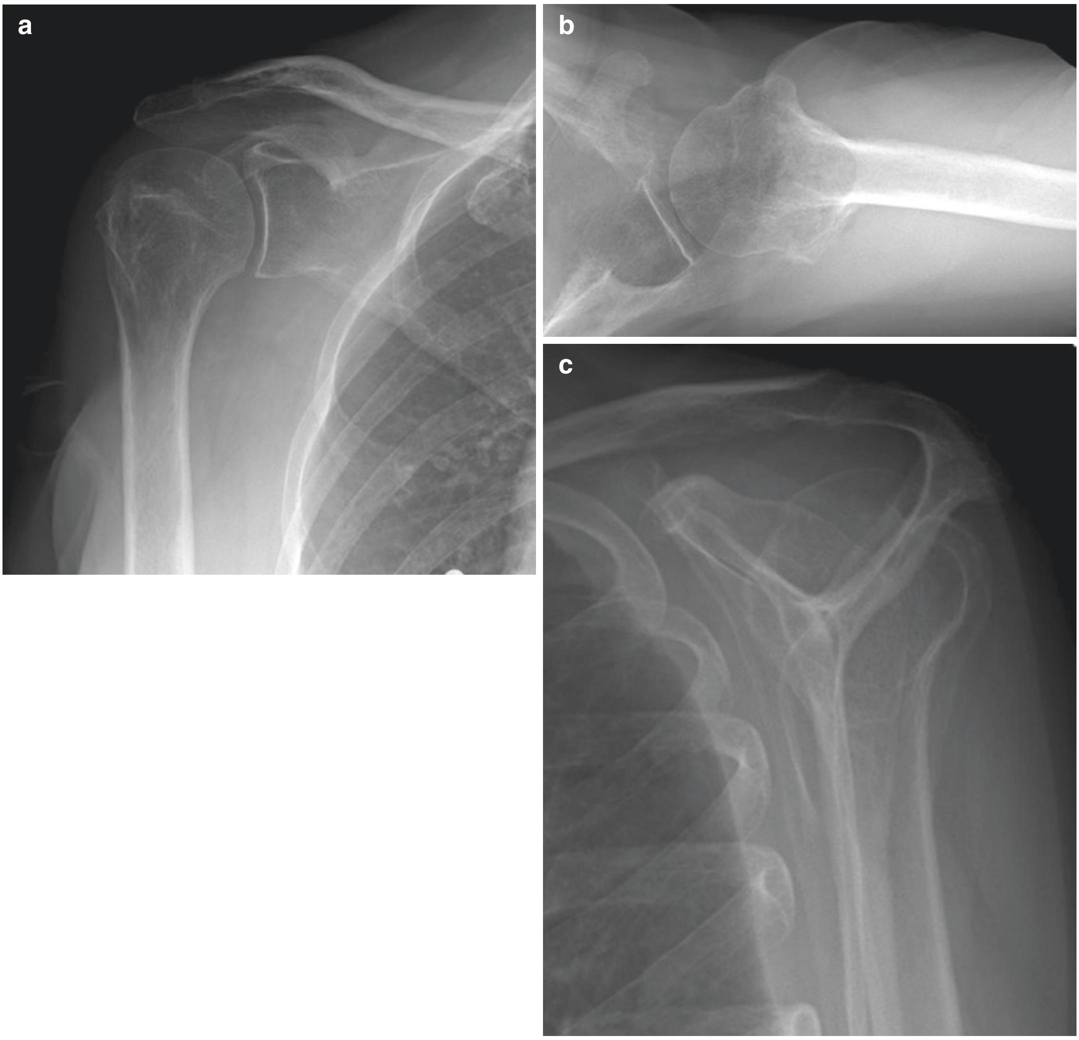

Fig. 12.3 (**a**–**c**) Anterior/posterior, axillary, and scapular Y views of a healed greater tuberosity fracture treated with arthroscopic reduction and fixation utilizing suture anchors in a double-row configuration

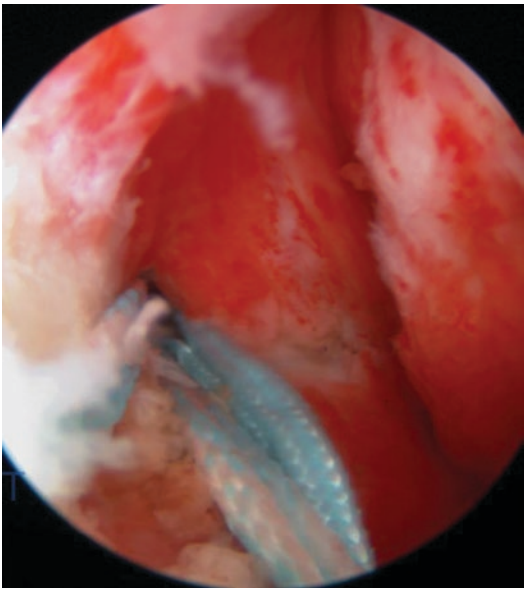

Fig. 12.4 Medial-row suture anchor placement for arthroscopic fixation of a greater tuberosity fracture

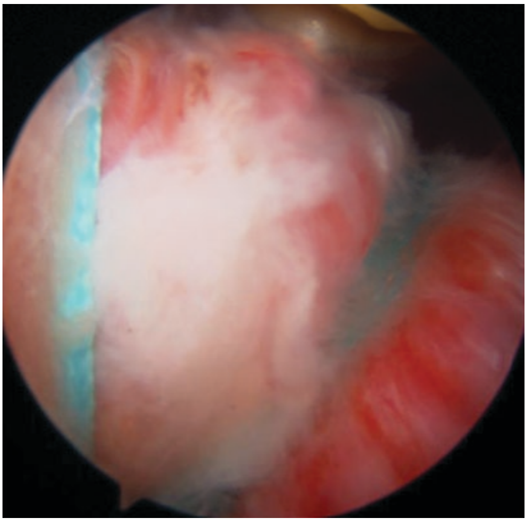

Fig. 12.5 Suture fixation of a greater tuberosity fracture using double-row technique

12.3 Rehabilitation

Various postoperative protocols have been described (Green and Izzi Jr. 2003; Ji et al. 2007; Taverna et al. 2004). Most researchers state that the postoperative rehabilitation is similar to that of a rotator cuff repair. There appears to be a consensus that sling immobilization with early pendulum exercises and passive range of motion is important to limit postoperative stiffness. Active range of motion is started between 4 and 6 weeks after surgery with strengthening exercises starting 8–12 weeks after surgery.

12.4 Outcomes

While good clinical results have been reported with open fixation of greater tuberosity fractures (Platzer et al. 1999), there is limited data related to arthroscopic fixation. In a study of a mixed cohort of patients with only a few being treated arthroscopically, Yin et al. (2012) reported good glenohumeral joint range of motion, shoulder pain scores, and patient-reported outcomes. Evaluation of greater tuberosity fractures treated by arthroscopic double-row suture fixation has shown improved visual analog pain scores, University of California, Los Angeles (UCLA), scores, and American Shoulder and Elbow Surgeons (ASES) scores. This same study reported good range of motion at a mean 2-year follow-up (Ji et al. 2010).

12.5 Conclusion

While humeral isolated greater tuberosity fractures are not common, surgical fixation use has increased as our understanding of the detrimental effect of fracture fragment displacement on shoulder function has on increased. Reduction and fixation have shown good results, but newer arthroscopic techniques allow for better visualization, stable fixation, and minimal damage to the surrounding tissues, while better enabling treatment of concomitant injuries. Further research into clinical outcomes following arthroscopic fixation of greater tuberosity fractures is needed.

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13

Arthroscopy-Assisted Reduction-Internal Fixation in Greater and Lesser Humeral Tuberosity Fracture

Bancha Chernchujit and Renaldi Prasetia

Proximal humerus fractures represent approximately 50% of all humerus fractures and approximately 5% of all fractures in humans (Horak and Nilsson 1975; Lewis et al. 2015). Although isolated lesser or greater tuberosity humeral fractures are less common, when they occur they warrant special treatment consideration. Isolated greater tuberosity fractures occur in 17–21% of proximal humeral fractures and 15–30% of glenohumeral joint dislocations (Bahrs et al. 2006; Green and Izzi 2003; Liao et al. 2016). Isolated lesser tuberosity avulsion fractures represent 2% of all proximal humerus fractures (Goeminne and Debeer 2012; Gruson et al. 2008; Lewis et al. 2015).

Several reports have proposed the injury mechanism for greater tuberosity fractures where the rotator cuff muscles cause an avulsion due to muscle action. A direct blow or fall onto the shoulder, or indirectly, such as falling on an outstretched upper extremity or on an abducted and externally rotated shoulder represents other greater tuberosity fracture mechanisms (Bahrs et al. 2006; Baudi et al. 2015). Lesser tuberosity fractures are related to the following three primary injury mechanisms: (1) an avulsion through the lesser tuberosity apophysis with the shoulder in a forced sudden abduction and external rotation and the subscapularis muscle eccentrically contracting to resist this force, (2) an axial load along the long axis of humerus applied to an extended and externally rotated shoulder, and (3) micro-trauma or repetitive trauma that creates an incomplete lesser tuberosity traction injury (Gruson et al. 2008; Lewis et al. 2015; Neogi et al. 2013; Robinson and Aderinto 2005).

Both lesser and greater tuberosity fractures are frequently associated with traumatic shoulder dislocations and axillary nerve injuries. However, other nerves such as the suprascapular, radial, and musculocutaneous nerve may also be injured. Associated neural injuries occur more commonly in elderly patients in association with soft tissue hematoma formation. Neural recovery generally takes 4 months or less (de Laat et al. 1994; Lewis et al. 2015; Toolanen et al. 1993). Arterial injuries may also be associated with tuberosity fractures that occur in conjunction with other proximal humerus fractures, glenohumeral fracture-dislocation, or frank glenohumeral dislocation (Lewis et al. 2015; Willis et al. 2005; Zuckerman et al. 1984). Glenohumeral joint labral, capsuloligamentous, rotator cuff lesions and articular cartilage damage may also occur in conjunction with tuberosity fractures (Schai et al. 1999).

The recent trend toward minimally invasive surgery has extended to surgical fracture management. The use of such procedures has the

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advantage of minimizing soft tissue damage using smaller incisions. This prevents further fracture region blood supply damage. Reduced soft tissue damage helps prevent postoperative infection and provides better cosmetic results (Barnes et al. 2010; Giudici et al. 2017).

13.1 Clinical and Imaging Evaluation

In the acute situation, it is not easy to clinically distinguish an isolated greater tuberosity fracture from a three- or four-part proximal humeral fracture or from acute rotator cuff injury. In each situation, the patient's chief complaint involves shoulder pain, and reduced or absent active mobility, particularly shoulder abduction and external rotation movements. A detailed history is essential to delineate the precise injury mechanism and the presence of any pre-existing shoulder conditions. A detailed, systematic physical examination is essential to help determine if any associated neurologic injuries exist. It can be difficult to precisely evaluate proximal upper extremity muscle strength in the presence of an acute injury. Sensory examination alone can be misleading, particularly with axillary nerve injury, as it is possible to have intact sensation while motor function is abnormal. Electrodiagnostic studies including electromyography and nerve conduction velocity tests should be obtained if the neurologic deficit does not resolve within 3–6 weeks (Green and Izzi Jr 2003; Gruson et al. 2008). In most cases, electromyography can confirm low-grade neuropraxia, related to stretch or external pressure from initial trauma, and can help map the recovery trajectory (Baudi et al. 2015).

Radiographic evaluation of the injured shoulder should always include the shoulder trauma series with a true anteroposterior (X-ray beam perpendicular to the scapular plane), scapula Y-view (X-ray beam parallel to the spine of the scapula), and Velpeau axillary view (with the patient standing, leaning backwards 30° over the X-ray table as the beam passes through the shoulder from above) (Fig. 13.1), (Green and

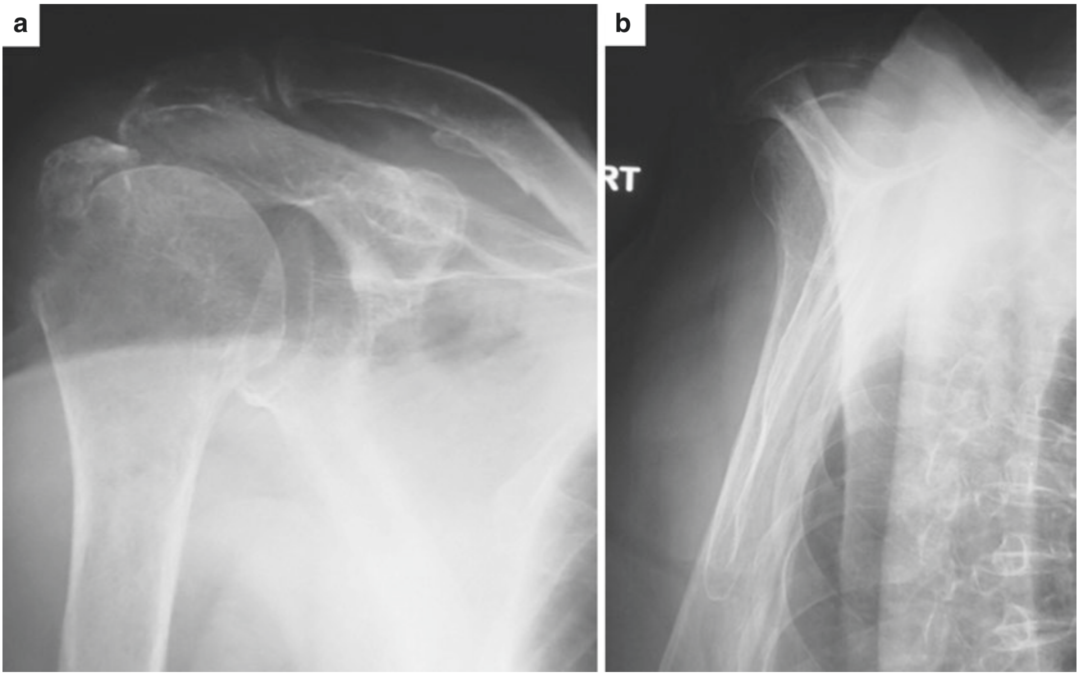

Fig. 13.1 Greater tuberosity humeral fracture. (**a**) Antero-posterior view. (**b**) Scapular-Y view

Izzi Jr 2003). Additional anteroposterior views in internal and external rotation can provide more details about the extent of supero-posterior greater tuberosity fracture displacement. Additionally, this X-ray view can help identify the presence of an occult, non-displaced humerus surgical neck fracture. Fracture displacement magnitude and pattern are critical to operative planning for humeral tuberosity fracture management. Additionally, this information helps when deciding if an arthroscopy-assisted surgical approach may be beneficial. Computed tomographic (CT) imaging may also be indicated to determine the number and pattern of fracture fragments, the direction and extent of displacement, occult fracture lines, and whether or not an intra-articular extension (three-part valgus impacted fractures) is present. This information may influence both the selected surgical approach and the choice of fixation device(s) (Gruson et al. 2008; Mora Guix et al. 2006). CT imaging should always be performed if plain radiographs do not adequately delineate displacement magnitude and provide adequate insight as to which surgical approaches should be considered. Axial imaging is most useful for demonstrating posterior displacement, but it may not always clearly demonstrate the extent of superior displacement. Coronal and three-dimensional reconstruction CT imaging could be used to better define the extent of superior greater tuberosity fracture displacement (Figs. 13.2 and 13.3).

Diagnostic ultrasound can be particularly helpful in trying to identify occult fractures in acute settings and provide accurate assessment of rotator cuff integrity when radiographic imaging is positive. The speed of performance, relatively low cost, and increasing availability in emergency departments make ultrasound particularly suited for diagnosing tuberosity fractures in emergency room settings and monitoring the clinical course after nonsurgical treatment (Green and Izzi Jr 2003; Patten et al. 1992).

Magnetic resonance imaging (MRI) is generally not indicated for tuberosity fracture evaluation. However, if plain radiographs fail to reveal a fracture, and the clinical course is not progressing satisfactorily, MRI can help identify the presence of an occult non-displaced greater tuberosity fracture, rotator cuff tear, or occult intra-articular injury (Gruson et al. 2008; Mason et al. 1999; Zanetti et al. 1999).

13.2 Indication for Surgical Intervention

There is no “gold standard” in terms of the surgical management of tuberosity fractures. Important factors to consider include which tuberosity has fractured, the extent of displacement, the direction of displacement, and amount of comminution. Additionally, important patient characteristic factors that should be considered include age, comorbidi-

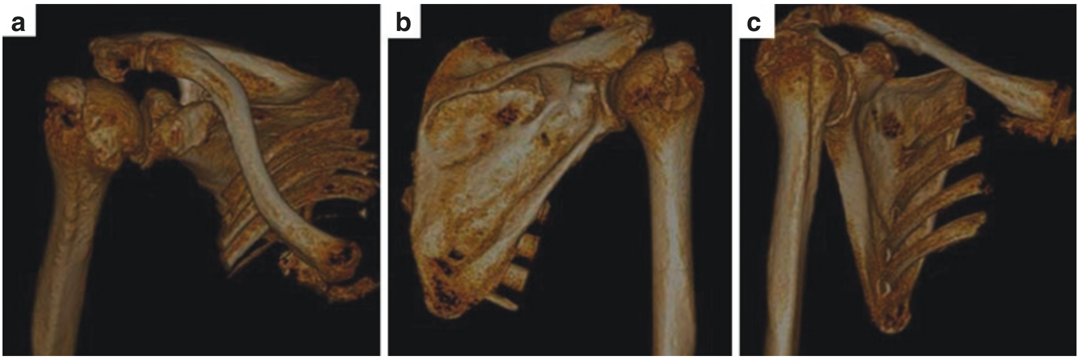

Fig. 13.2 CT-3D reconstruction (right shoulder). (**a**) Antero-posterior view. (**b**) Posterior view. (**c**) Anterior oblique view

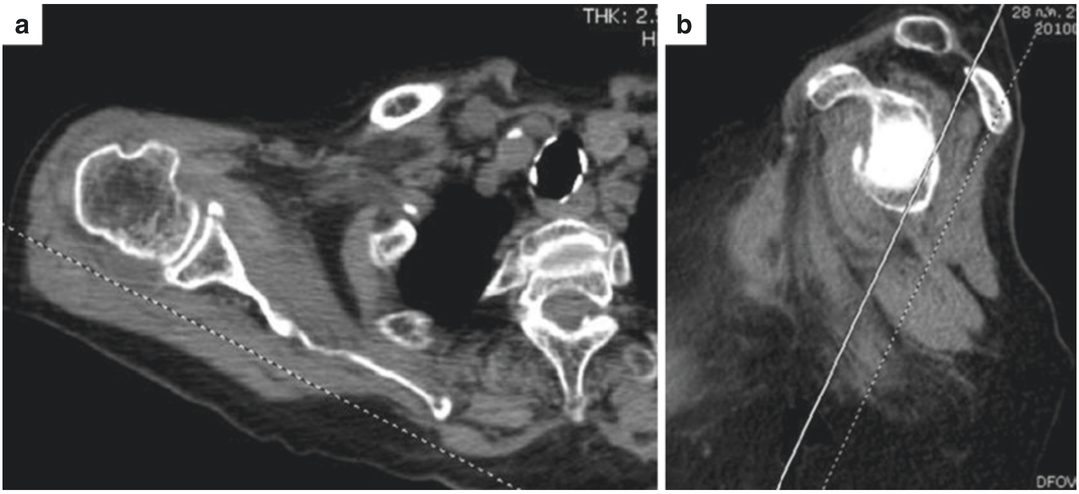

Fig. 13.3 CT- 2D (right shoulder) (**a**). Axial view (**b**). Sagittal view showing bone fragment at antero-inferior glenoid

ties, bone quality, dominant or non-dominant hand, and patient activity level (Baudi et al. 2015).

Neer (1970) initially recommended operative treatment when displacement was greater than 1 cm. Later, Bigliani and Flatow (1998) and Park et al. (1997) changed the indication to 5 mm. For younger, more active patients, athletes, or heavy manual workers, Resch et al. (1992) recommended 3 mm dislocation. More recently, Baudi et al. (2015) recommended that fracture displacement direction should be a surgical decision-making factor since superior or posterosuperior displacement is less tolerable for patients and more likely to cause subacromial impingement. These researchers recommended surgical treatment for superior or posterosuperior displacements greater than 3 mm, especially in young or active patients, athletes, or heavy laborers. Posterior displacement up to 5 mm is better tolerated, especially in the absence of an associated anterosuperior rotator cuff tear (Baudi et al. 2015). Gruson et al. (2008) suggested that this displacement could be increased to 1 cm in elderly patients with comorbidities who possess limited functional activity expectations (Gruson et al. 2008).

For lesser tuberosity fractures, the accepted indications for surgery include fragment displacement of 5 mm or 45° of angulation, having a mechanical block to internal rotation, continued pain, and weakness of internal rotation (Gruson et al. 2008).

Arthroscopy-assisted reduction-internal fixation (ARIF) for tuberosity fracture management is considered in cases of slight tuberosity fracture fragment displacement (3–10 mm). Fragment size and the degree of comminution are important factors when determining the type of fixation. The presence of a single large fragment, i.e., more than 2 × 2 cm or 3 × 3 cm, may allow for fixation with one or two screws. In osteoporotic bone, our recommendation is to use a screw combined with a tension band to reduce rotator cuff traction forces and facilitate earlier mobilization. In the presence of a small fragment that is less than 2 × 2 cm or that is comminuted and osteoporotic, we prefer suture anchor fixation in suture bridge fashion (Li et al. 2017; Vester et al. 2015). This technique can buttress the fracture fragment and maintain fracture reduction and soft tissue preservation. Appropriate contact pressure restoration using the tension band principle helps to promote bone healing and facilitate early shoulder mobilization.

13.3 Surgical Technique: Arthroscopy-Assisted Humeral Tuberosity Fracture Fixation

13.3.1 Position: Portal Placement

The patient is placed in the beach-chair position (Fig. 13.4a). A standard posterior portal is used for diagnostic arthroscopy. An anterosuperior portal is placed just anterior to the acromioclavicular joint. The lateral border of the acromion is divided into three equal parts by two lines. An anterolateral portal is created 2.5 cm laterally on the anterior line, and a posterolateral visualization portal is created 1 cm lateral to the posterior line. In lesser tuberosity fracture cases, an anteroinferior portal to perform suture management and medial-row knot tying using a 7-mm threaded arthroscopy cannula is added (Fig. 13.4b).

13.3.2 Diagnostic Arthroscopy: Subacromial Decompression

Diagnostic arthroscopy is performed to identify and treat any intra-articular pathology, such as labrum tear, long head biceps tendon lesion or entrapment, intra-articular surface rotator cuff (subscapularis, supraspinatus, infraspinatus) tear, a fracture extending intra-articularly, and a glenoid fracture. The arthroscope is shifted to the subacromial region, and acromioplasty is performed if indicated. Bursectomy is performed to improve visualization.

13.3.3 Greater Tuberosity Fracture Exposure: Fragment Identification—Reduction and Fixation

A shaver through the posterior portal is used to facilitate better visualization by evacuating blood clots and hemarthrosis. The location where the supraspinatus tendon-greater tuberosity fragment attaches to the humerus is then determined. Following this, debridement is performed on the undersurface of the fragment and at the fracture site.

At this point, displacement magnitude and the potential to perform fragment reduction, fragment size, and the degree of comminution are evaluated. The algorithm, to determine the preferred reduction and fixation technique, is showed in Fig. 13.5. If the fragment displacement is slight and the fragment size is more than 3 × 3 cm, we perform fixation using a percutaneous screw under fluoroscopy guidance with arthroscopic assistance.

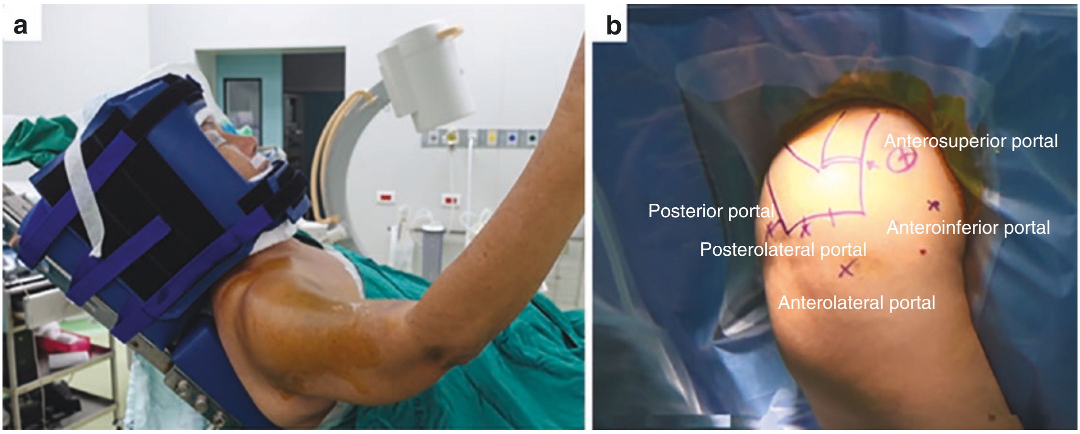

Fig. 13.4 (**a**) Beach-chair position. (**b**) Portal placement for arthroscopy assisted reduction–fixation

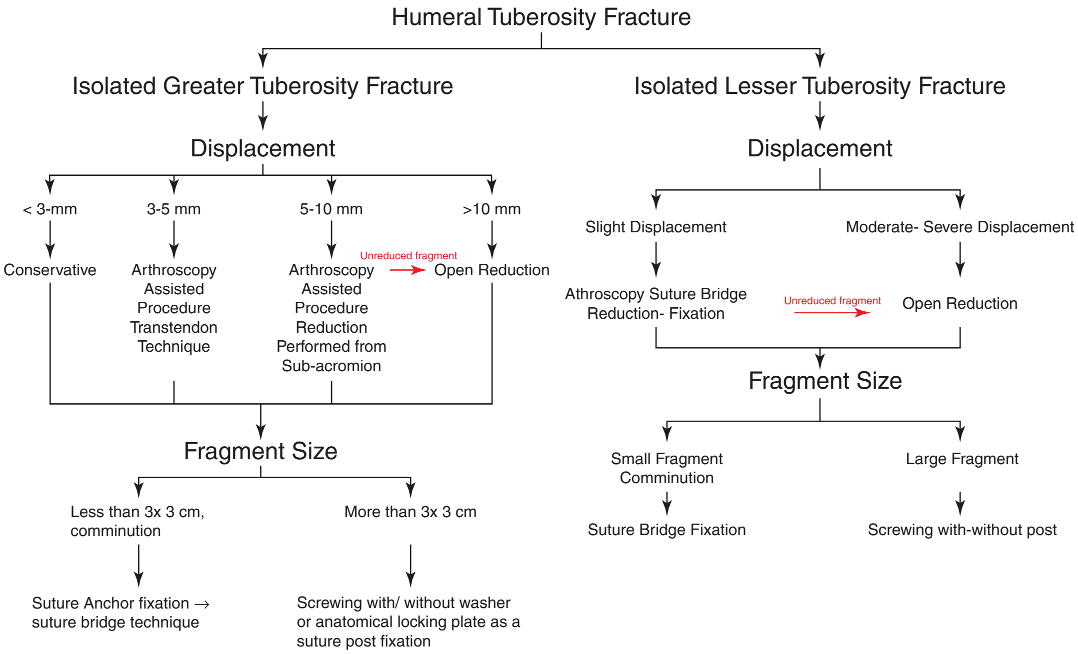

Fig. 13.5 Algorithm for isolated tuberosity humeral fracture management

If fragment displacement is 3–5 mm and the junction between the humeral head articular cartilage, if fragment size is less than 3 × 3 cm and/or comminuted, we prefer reduction and fixation using a suture bridge technique and a transtendon repair principle. Subsequently, a suture anchor is inserted at the articular margin of the humeral head through the intact rotator cuff, serving as a medial-row anchor. The exact suture placement location is managed under direct intra-articular visualization from the posterior portal, using a bird-beak instrument. A second suture anchor is then placed at the medial fracture site margin, and its suture strands are shuttled through the intact rotator cuff in a similar manner (Fig. 13.6a). Then, the arthroscope is moved into the subacromial space. The suture strands of medial-row anchors are then tied with a sliding knot under direct visualization. A posterolateral portal is created for visualization purposes, and a switching stick is used to shift the camera to the posterolateral viewing portal. The lateral fracture line is then re-identified. The anterolateral working portal is used for suture management and anchor placement. To avoid soft tissue interposition, a partially threaded 7-mm cannula is inserted into the anterolateral portal. A pilot hole is then created from the anterolateral portal, and the lateral-row anchor site is placed approximately 5–10 mm distal to the most lateral fracture line, just posterior to the bicipital groove. Then, both ends of the same suture are retrieved through the cannula. The anchor is inserted through the cannula while the strands are held firmly, ensuring smooth sliding of the anchor on the threads. The anchor is hammered into the pilot hole until the threads start entering the hole. Then, all strands are tightened one by one, and the anchor is fully secured. The position of the second lateral-row suture-less anchors should be 10 mm posterior to the first one, using the same protocol to create a suture bridge (Fig. 13.6b). Good reduction can be achieved using this technique with a stable construct and no tension at the repair site.

If fragment displacement is 5–10 mm, where the junction between the humeral head articular

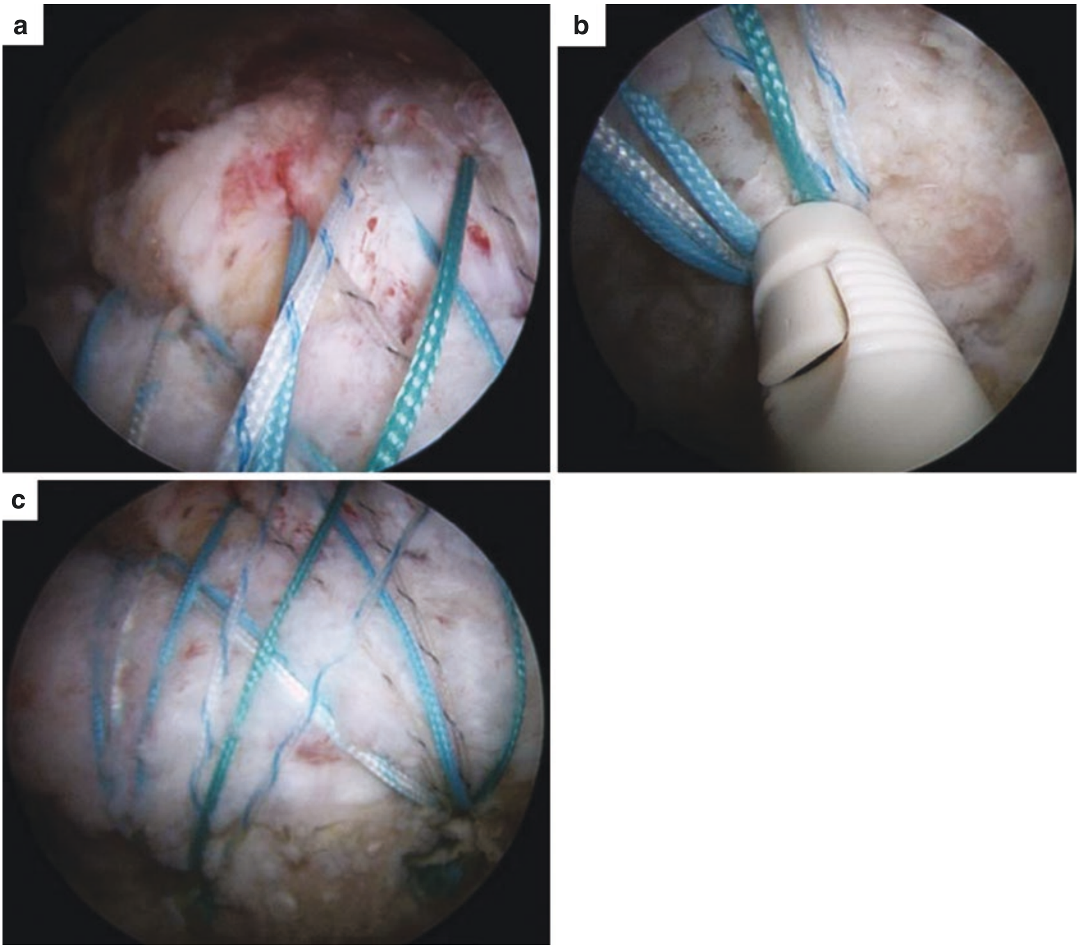

Fig. 13.6 (**a**) Medial suture strands insertion at bone-tendon junction. (**b**) Lateral row suture anchorage. (**c**) Suture bridge configuration for greater tuberosity humeral fixation

cartilage and the bone crater can be identified, and the fragment size is less than 3 × 3 cm and/or comminuted, reduction and fixation using a suture bridge technique in the same fashion as when performing a rotator cuff repair is performed. A posterolateral portal is created for visualization, and a switching stick is used to shift the camera to the posterolateral viewing portal. Posterior and anterosuperior portals are used for inserting the suture strands to the bone-tendon junction, using a cuff passer instrument, whereas the anterolateral working portal is used for suture management and anchor placement. A partially threaded 7-mm cannula is inserted into the anterolateral portal to avoid soft tissue interposition. We refresh and debride the bone crater (the raw surface where the fragment will be placed). Then, we put two medial double-loaded anchors at the articular cartilage-bone crater junction from the anterosuperior portal. A rotator cuff repair passer is used to insert the suture strands to the medial part of bone (greater tuberosity fragment) and supraspinatus tendon junction through the posterior or anterior-superior portal. Two different colored suture strands from each anchor are penetrated into the bone and tendon junction. In total, four penetrations are created with two threads in each hole. The distance between the two holes should cover the width of the tuberosity fragment. The suture bridge is created in the manner previously mentioned (Fig. 13.6c).

If the fracture or tuberosity fragment cannot be reduced to acceptable alignment, conversion to an open procedure is necessary, using a deltopectoral or deltoid splitting approach. With this approach, fixation can be performed using a locking plate as a suture post or suture anchor, similar to the suture bridge technique (Fig. 13.7a–d).

13.3.4 Lesser Tuberosity Fracture Exposure: Fragment Identification—Reduction and Fixation

An arthroscopy-assisted procedure for reduction and fixation of lesser tuberosity requires working in the subcoracoid space. Good visualization is mandatory for each step of this procedure. After diagnostic arthroscopy to identify any other intra-articular pathology and to confirm lesser tuberosity fracture, we evaluate the condition of the long head of the biceps tendon, which often is

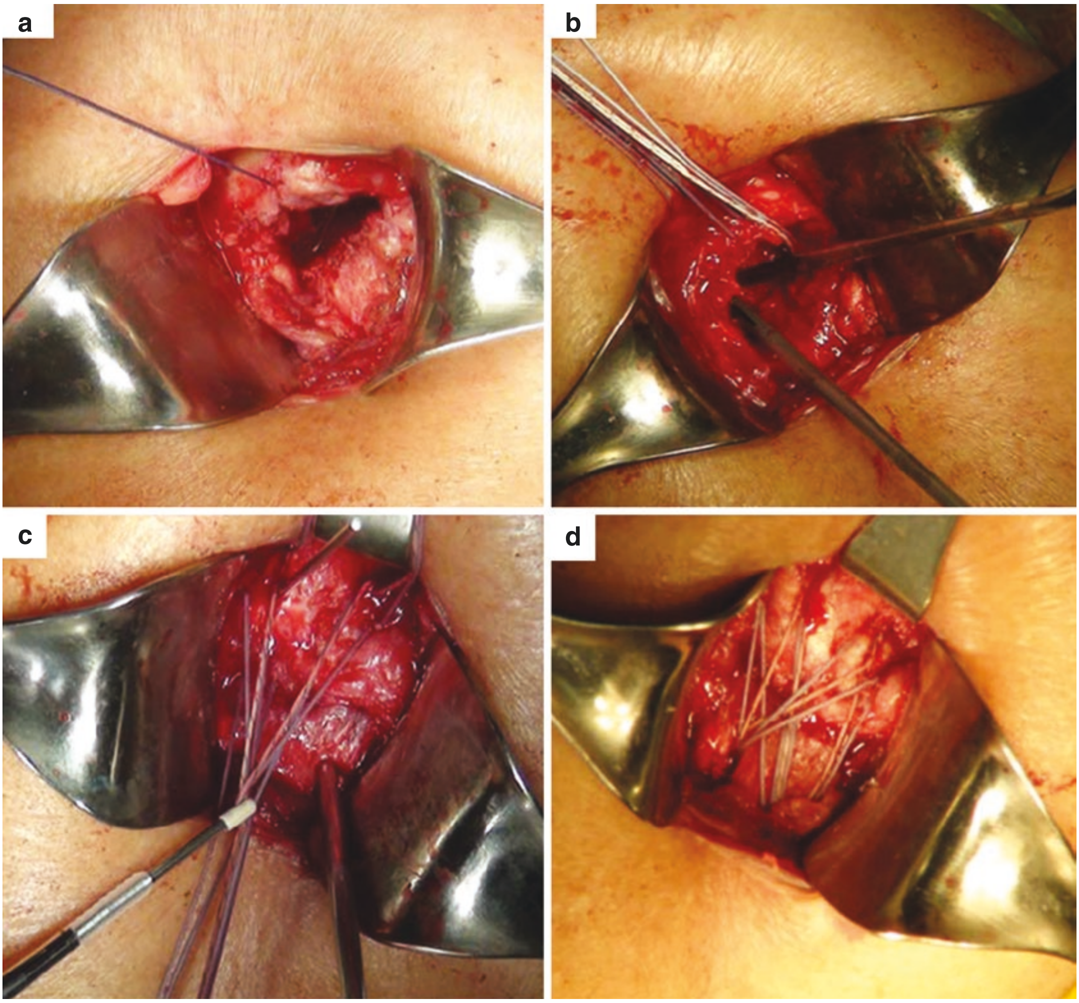

Fig. 13.7 Mini-open procedure of isolated greater tuberosity fixation. (**a**) Greater tuberosity avulsion fracture. (**b**) Medial row suture anchorage. (**c**) Lateral row suture anchorage. (d) Mini- open reduction-suture bridge fixation for greater tuberosity humeral fixation

entrapped between the fracture fragment(s), thereby obstructing reduction. In this situation, we perform biceps tenotomy or tenodesis to facilitate lesser tuberosity reduction and fixation. Through the anterosuperior portal, we perform a tenotomy of the long head of the biceps tendon.

Accessing the subcoracoid space is important to perform arthroscopy-assisted lesser tuberosity fixation. A shaver or electrocautery device is used to make an opening in the rotator interval just superior to the subscapularis tendon. The coracoid is usually hidden beneath a bursa that extends from the lateral border of the subscapularis to the anterior internal deltoid fascia.

A double-loaded suture anchor is first inserted into the fracture site through the anterosuperior portal (Figs. 13.8a and 13.9a). By means of a rotator cuff stitch, the subscapularis tendon is perforated immediately adjacent to the bone-tendon interface at the most inferior aspect from the anteroinferior portal. This suture strands can also be used to reduce the fracture fragment (Fig. 13.8b). Then, the two suture strands (different color) are retrieved through the anterosuperior portal, connected to loop end limb as a shuttle suture relay (Fig. 13.9b). The last two suture strands are also retrieved through the bone-tendon junction superior to the previous penetra-

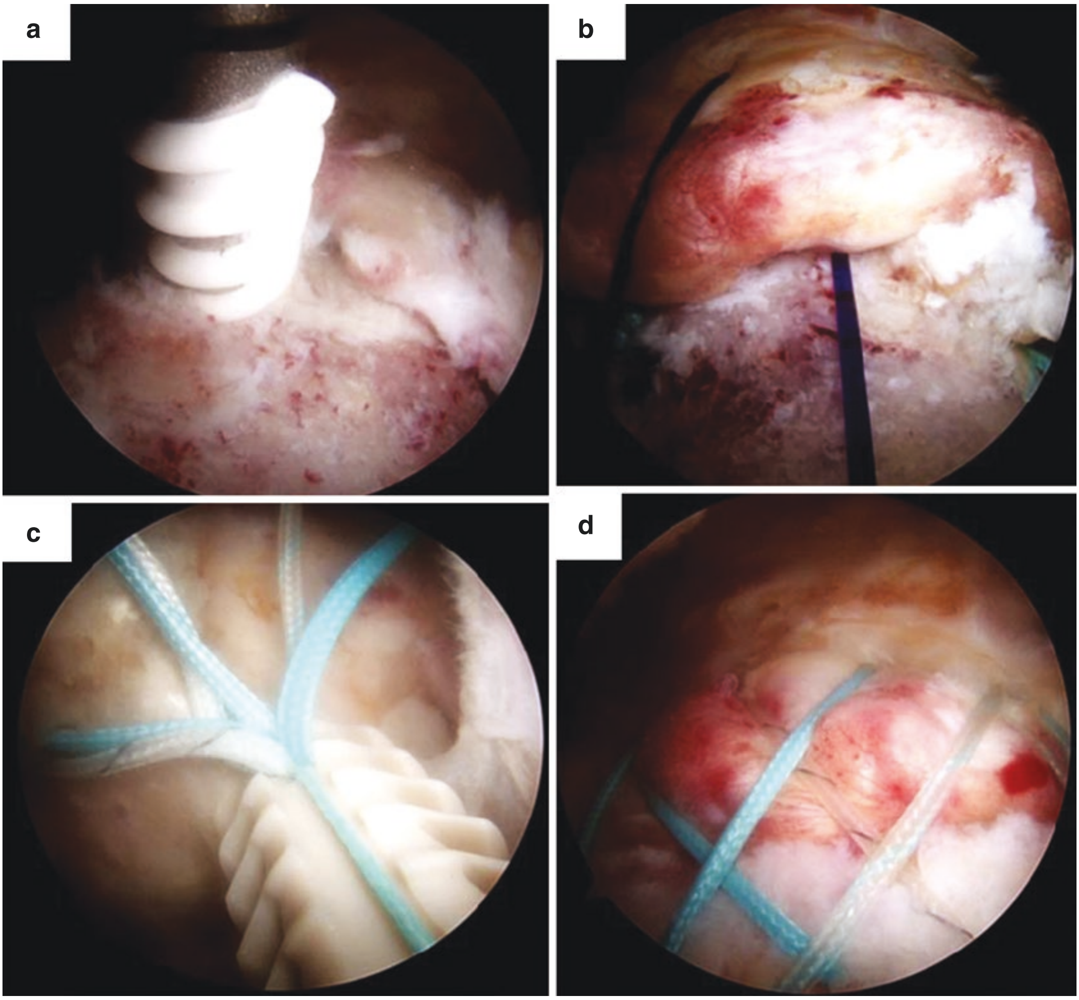

Fig. 13.8 Arthroscopic view of arthroscopy-assisted lesser tuberosity reduction and fixation. (**a**) Medial row suture anchorage. (**b**) Suture traction to assist reduction at bone-tendon junction. (**c**) Lateral row suture anchorage. (**d**) Suture bridge fixation of lesser tuberosity fracture

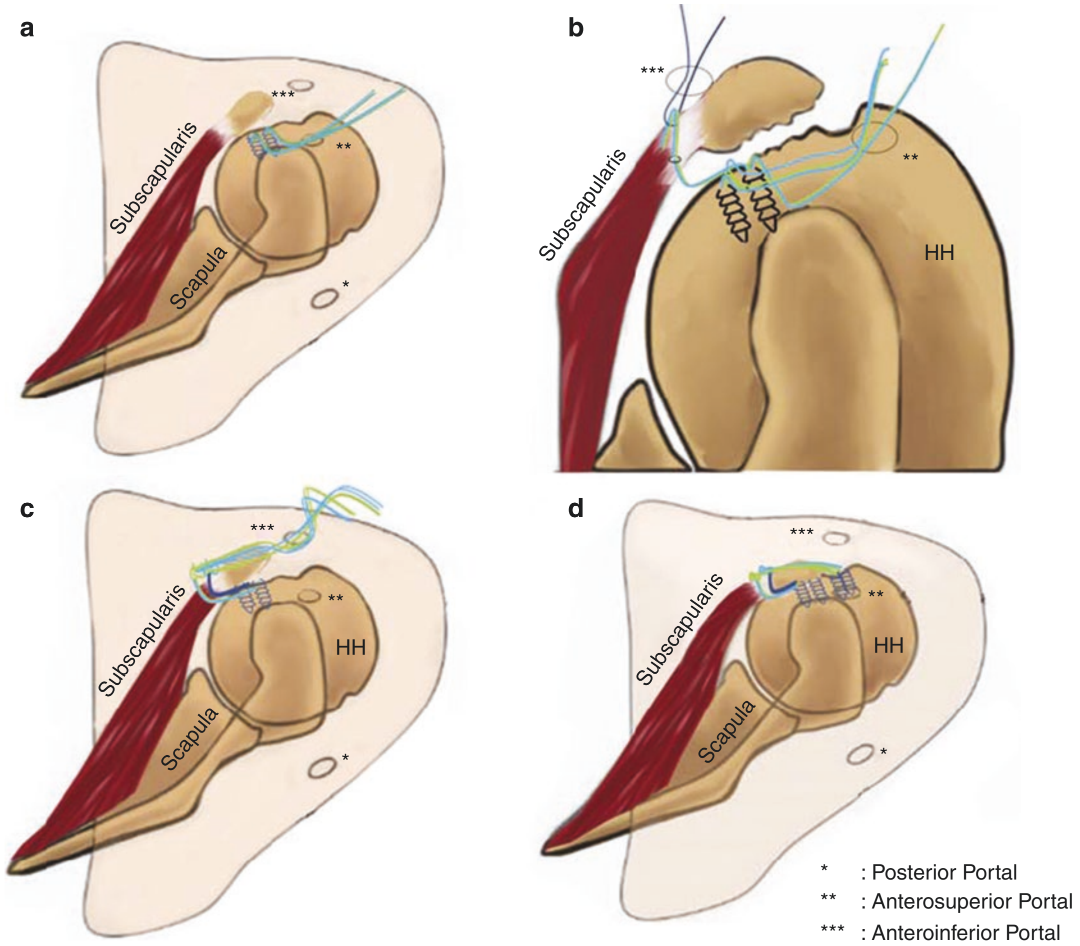

Fig. 13.9 Arthroscopy-assisted lesser tuberosity reduction and fixation. (**a**) Medial row suture anchorage. (**b**) Suture shuttle relay at bone-tendon junction. (**c**) Anteroinferior portal for suture management. (**d**) Lateral row suture anchorage as suture bridge fixation of lesser tuberosity fracture

tion (Fig. 13.9c). To increase the fracture coverage area and the initial fixation strength of the reduced fragment, a second double-loaded suture anchor is inserted into the raw fracture bed area. Using the same technique as described earlier, further bone-tendon junction penetrations are then performed. Then, knot tying is done at the medial row of pair suture strands between the first and second hole and between the third and fourth hole.

A pilot hole is then created from the anteroinferior portal, to position the lateral-row anchor site close to the bicipital groove. Then, both ends of the same suture are retrieved through the cannula, using four ends of two suture strands. The remaining suture strands are retrieved in the anterosuperior portal to avoid suture entangling. The anchor is inserted through the cannula while the threads are held firmly, ensuring smooth sliding of the anchor on the threads. The anchor is hammered into the pilot hole until the suture strands start entering the hole (Fig. 13.8c). Then, all suture strands are tightened one by one. The remaining threads are retrieved through the anteroinferior cannula, and a suture-less anchor is used to secure the threads in position. The position of second lateral-row anchors should be 10 mm inferior to the first one, using the same protocol to create a suture bridge (Figs. 13.8d and 13.9d). Good reduction can be achieved using this technique with a stable construct and no tension at the repair site. If the fracture or tuberosity fragment cannot be reduced to acceptable alignment, conversion to an open procedure using a deltopectoral approach should be performed. With this approach, fixation can be performed using a locking plate as a suture post or suture anchor similar to the suture bridge technique (Fig. 13.10).

13.4 Postoperative Rehabilitation

Following arthroscopy-assisted greater tuberosity fracture fixation, the affected upper extremity is placed in a sling for the initial 3 post-surgical weeks. Pendulum exercises are initiated immediately, followed by passive motion exercises with forward shoulder flexion, internal rotation, and external rotation at waist level (shoulder adducted) for 6 weeks under the supervision of a

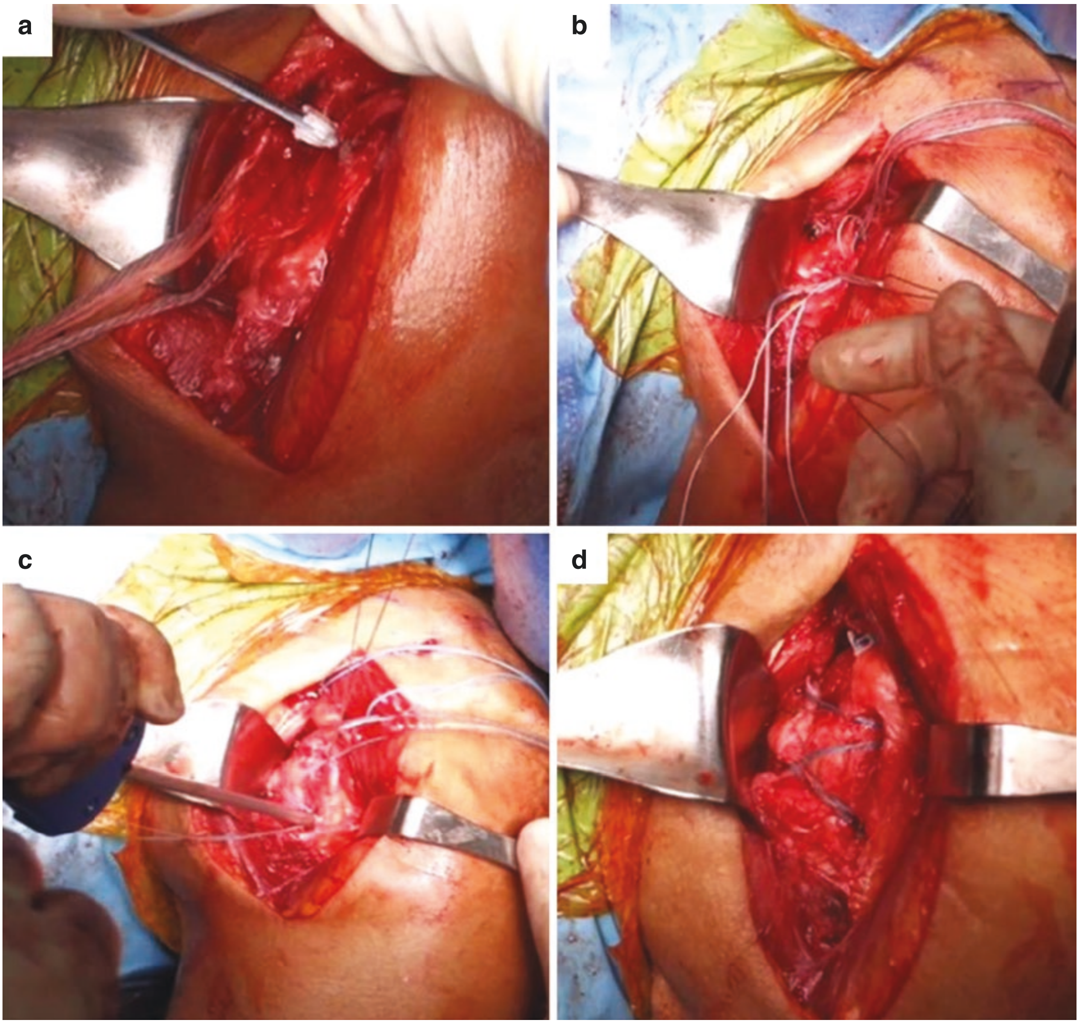

Fig. 13.10 Open procedure of isolated lesser tuberosity fixation. (**a**) Medial row suture anchorage. (**b**) Threads penetration to bone-tendon junction. (**c**) Lateral row suture anchorage. (**d**) Open reduction-suture bridge fixation for greater tuberosity humeral fixation

physiotherapist. Early shoulder abduction-external rotation or abduction of the shoulder to more than 90° is avoided during this 6-week period. At 6–8 weeks post-surgery, active and active-assisted range-of-motion and mild shoulder strengthening exercises are initiated. Isometric rotator cuff strengthening exercises are started at 3 months and are continued until 6 months post-surgery with a progressive exercise program.

In terms of arthroscopic reconstruction of isolated lesser tuberosity fractures, more conservative rehabilitation protocols are necessary to protect the repair during the initial 6-week period. The affected upper extremity is placed in a sling for the initial 3 weeks post-surgery. Early supervised passive motion exercises are initiated; however, motion is restricted to 90° of shoulder flexion, 60° of abduction, and internal rotation over the first 4 weeks post-surgery. External rotation is limited to 0°, and patients are instructed to avoid active internal rotation during the initial 6 weeks post-surgery. Patients are recommended active-assisted and active shoulder range-of-motion exercises at 6 weeks post-surgery and begin isometric exercises at 3 months post-surgery (Scheibel et al. 2005).

13.5 Discussion

Over the last two decades, several advancements in the management of displaced greater and lesser humeral tuberosity fractures have occurred. Because the rotator cuff tendons attach to the humeral tuberosities, fracture displacement can cause impingement (subacromial impingement related to greater tuberosity malposition or subcoracoid impingement related to lesser tuberosity malposition) and range of motion limitations (abduction-external rotation limitations for greater tuberosity malposition and internal rotation limitation for lesser tuberosity malposition).

There is a growing role for arthroscopic approaches to assist tuberosity fracture reduction and fixation. The arthroscopic techniques are suitable in cases of limited fracture displacement and smaller fragments. There are several advantages to perform arthroscopy-assisted techniques, such as direct visualization, minimum invasiveness compared with large arthrotomy with a relatively narrow visual field of the joint space, superior intra-articular fracture reduction and fixation accuracy, and potentially improved clinical outcomes (Atesok et al. 2011). In a retrospective controlled study, Liao et al. (2016) reported on a large series of patients who were treated surgically for displaced greater tuberosity fractures. In that study, they compared a double-row suture bridge technique with suture anchors implanted arthroscopically with open reduction and internal fixation utilizing a proximal humeral locking plate via the deltopectoral approach. They found that both techniques were effective for fracture healing and both groups had few complications. However, the arthroscopy-assisted technique group had superior results in terms of shoulder flexion and abduction postoperatively and required less time in the operating theater (Liao et al. 2016).

Some limitations may also exist using the arthroscopy-assisted tuberosity fracture fixation. This procedure requires considerable technical skills and there is a long learning curve. Arthroscopic procedures cannot be mastered via current operating room education alone; there is a growing need for alternative educational methods such as cadaveric surgery laboratories, anatomical models, and computer simulation modules to improve trainee technical performance in the operating theater (Atesok et al. 2011).

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Arthroscopic-Assisted Surgery of the Distal Humeral Fractures

14

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14.1 Introduction

Distal humerus fractures in adults are relatively uncommon injuries, representing 0.5 to 2% of all fractures but up to 30% of fractures of the elbow (Ilyas and Jupiter 2008; Robinson et al. 2003; Rose et al. 1982; Webb 2001). Although fractures of the distal part of the humerus are rare in adults, there has been a substantial increase in their incidence among the elderly, mainly with osteoporotic bone (Nauth et al. 2011; Palvanen et al. 2010).

Bicolumnar fractures are the most common distal humeral fractures. They account for as many as 70% of distal humeral fractures in adults. These fractures involve injury to both the medial and lateral columns, disrupting the humeral triangle and resulting in disassociation of the articular surface from the humeral shaft (Pollock et al. 2008). Single-column fractures are relatively rare and account for only 3–5% of distal humeral fractures. Lateral column fractures are more common than medial column fractures. These fractures include the distal area of the respective column, including a portion of the articular surface (Wong and Baratz 2009). Fractures of the articular surface of the capitellum or trochlea are a distinct, complex subgroup, distinguished from single and bicolumn fractures (Watts et al. 2007). These coronal shear fractures of the distal humerus, which involve the capitellum and trochlea, account for less than 1% of elbow fractures (Grantham et al. 1981; Lee and Lawton 2012; Yari et al. 2015).

14.2 Classifications

No perfect classification system has been developed for distal humeral fractures that allows accurate direction for treatment. Commonly mentioned distal humeral fracture classification systems include Mehne and Matta and the AO/OTA classification (Jupiter and Mehne 1992).In the Mehne and Matta (based on Jupiter's model) classification system, according distal humerus

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fracture line pattern, fractures are described anatomically as a high or low "T," "Y," "H," and medial or lateral lambda fracture (Davies and Stanley 2006; Doornberg et al. 2006; Riseborough and Radin 1969; Sheehan et al. 2013). This classification has three main categories, intra-articular, extra-articular intracapsular, and extra-articular extracapsular. The intraarticular group is further subdivided into bicolumn, single column and articular fractures. The extra-articular intracapsular group consists of high and low transcolumn fractures, and the extracapsular group has medial and lateral epicondylar fractures. Y- and T-fractures begin in the center of the trochlea, causing propagation of the fracture vertically and across each column; if a fracture involves both columns at a distal level, it may enter the olecranon and coronoid fossae and produce comminuted articular fragments too small to reconstruct (Doornberg et al. 2006; Gradi and Jupiter 2012; Jupiter and Mehne 1992).H-type fractures may produce a free-floating trochlear fragment, with the medial column fractured in two places. This can increase the risk of avascular necrosis of the articular fragment (Table 14.1).

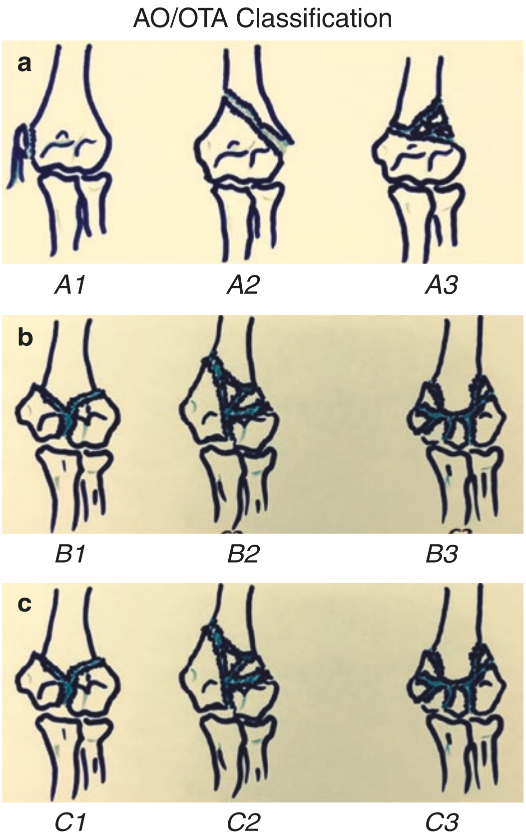
The AO/OTA classification system is based on articular and columnar involvement, as well as the degree of comminution (Table 14.2). Fractures are classified into three main types: type A (extra-articular), type B (partially articular), and type C (complete articular). These three types are then subdivided in three subtypes numbered as 1, 2, and 3, indicating increasing degrees of comminution or to further define the location of the fracture (Ilyas and Jupiter 2008; Muller et al. 2005; Robinson et al. 2003).Type A (extra-articular) fractures may involve the epicondyles or occur at the distal humeral metaphyseal level. Type B fractures are partially articular, because there is continuity between the humeral shaft and the articular segment. Type B fractures are unicondylar fractures in the sagittal or frontal plane. Frontal or coronal plane shear fractures are subclassified based on their location (capitellum, trochlea, or both). Type C fractures are termed complete articular, meaning there is no continuity between the articular segment and the humeral shaft. Type C fractures are further subclassified into simple (C1), simple articular with metaphyseal fragmentation (C2), and fragmentation of the articular surface and metaphyseal zone (C3).

Table 14.1 Mehne and Matta classification

Mehne and Matta classification	
High T	Transverse fracture proximal to or at upper olecranon fossa
Low T	Transverse fracture just proximal to trochlea (common)
Y	Oblique fracture line through both columns with distal vertical fx line
H	Trochlea is a free fragment (risk of avascular necrosis)
Medial lambda	Proximal fracture line exists medially
Lateral lambda	Proximal fracture line exists laterally
Multiplane T	T type with additional fracture in coronal plane

Table 14.2 AO/OTA classification

Distal humerus fractures: AO/OTA classification		
Type	Description	
Type A	*Extra-articular fractures* 13-A1: Apophyseal avulsion 13-A2: Metaphyseal simple 13-A3: Metaphyseal multifragmentary (comminuted)	
Type B	*Partial articular fractures* 13-B1: Sagittal lateral condyle 13-B2: Sagittal medial condyle	
	13-B3: Frontal	13-B3.1: Capitellar fractures
		13-B3.2: Trochlear fractures
		13-B3.3: Capitellar and trochlear fractures
Type C	*Complete articular fractures* 13-C1: Articular simple, metaphyseal simple 13-C2: Articular simple, metaphyseal multifragmentary (comminuted) 13-C3: Articular, multifragmentary (comminuted)	



Isolated coronal plane fractures of the distal humeral articular surface have also been described and classified in the literature. They represent shear-type injuries involving the capitellum, trochlea, or both. It is important to recognize that these injuries can occur as isolated or in association with other fractures of the distal humerus, the radial head, or the olecranon (McKee et al. 1996; Ring et al. 2003). The most commonly used classification system for coronal shear fractures was originally described by Bryan and Morrey (1985) and later modified by McKee et al. (1996) (Table 14.3). In this classification system, based on radiographs, type I represents a coronal shear fracture of the capitellum (Hahn-Steinthal fracture), type II is an osteochondral lesion of the capitellum (Kocher-Lorenz fracture), type III is a comminuted fracture of the capitellum, and type IV represents a fracture of the capitellum with medial extension encompassing part or all of the trochlea (McKee et al. 1996).

Table 14.3 Bryan and Morrey classification

Bryan and Morrey classification—coronal shear fractures	
Type I	These are isolated capitellar fractures involving a large portion of cancellous bone; they are known as Hahn-Steinthal fractures
Type II	These are fractures involving the anterior articular cartilage, with a thin-sheared layer of subchondral bone; they are known as Kocher-Lorenz fractures
Type III	These are comminuted osteochondral fractures
Type IV	Classified by McKee et al. (1996), these involve the capitellum and one half of the trochlea; they often result in the double-arc sign observed on lateral radiographs

The AO/OTA classification system denotes these coronal shear fractures as 13-B3-partial articular distal humeral fractures in the frontal plane. They are further subclassified as B3.1, indicating isolated capitellar fractures; B3.2, trochlea fractures; or B3.3, capitellum and trochlea fractures with a secondary fracture line in the sagittal plane. Capitellum and trochlea fractures may also be components of more complex, multifragmentary intercondylar fractures (Marsh et al. 2007; Ring et al. 2003).

14.3 Diagnosis

14.3.1 Mechanism of Injury

Distal humeral fractures occur from falling on an outstretched hand, falling from a height and landing directly on the elbow, road traffic accident, sports-related accident, or assault/direct blow (Watts et al. 2007). Complete distal humeral fractures result from impaction of the proximal ulna on the articular part (trochlea, capitellum) of the distal humerus. The impact can occur while the elbow is flexed or extended. If the elbow is flexed at impact, the articular fragments move forward; if the elbow is extended, they typically move backwards (Bégué 2014; Jupiter and Morrey 1993).Partial sagittal plane fractures of the lateral or medial condyle occur in indirect trauma with a valgus or varus position, while the elbow is in full or nearly full extension. These fractures are accompanied by capsular and ligament injuries, which result in an unstable elbow (Behrman and Shelton 1990; Leet et al. 2002; Min et al. 2010; Sullivan 2006). Capitellar fractures are the result of shear forces. The most common mechanism is the transmission of an axial force through the radial head on the capitellum and the lateral ridge of trochlea. The capitellum is vulnerable to shearing fractures in the coronal plane because its center of rotation is 12–15 mm anterior to the humeral shaft (Hotchkiss and Green 1991; Jupiter and Morrey 1993; Watts et al. 2007).

14.3.2 Clinical Diagnosis

The clinical appearance of distal humeral fractures can be described as a painfully swollen elbow with deformity and functional disability. The elbow may appear angulated and palpable crepitus may also be present. The clinical diagnosis of complete or partial sagittal fractures is not particularly difficult. However, coronal shear fractures of the capitellum or trochlea can go unrecognized. In these fractures the elbow shape is normal; and there might be minimal swelling and tenderness on the lateral elbow, with minimal functional loss. The functional deficit will reveal itself on passive or active flexion or extension (Bégué 2014; Hotchkiss and Green 1991).

Neurovascular status must be carefully evaluated and monitored in distal humeral fractures; this may in fact be more important in elbow fractures than most other fractures of the body. An accurate assessment should be made of the sensory and motor contributions of the median, ulnar, and radial nerves, as well as the medial and lateral antebrachial cutaneous nerves. It is important to determine if the ulnar nerve is injured, as it will need to be transposed during the fixation process. The brachial artery lies anterior to the elbow joint and is at risk for disruption. The distal pulses should be palpated, and the capillary refills should be assessed, with comparisons made to the contralateral upper extremity (Athwal et al. 2008; Chen et al. 2010; Milch 1964). Severe pain and the inability to tolerate finger extension, whether active or passive, may suggest the possibility of compartment syndrome (Hausman and Panozzo 2004; John et al. 1994).

14.3.3 Imaging

The details of fracture presentation such as bone quality, pattern, comminution level, articular surface involvement, displacement, and associated injuries must be fully understood before treatment is executed (Doornberg et al. 2006). Standard anteroposterior and lateral radiographs of the elbow are usually sufficient for diagnosis, classification, and surgical templating (Sheehan et al. 2013). The anteroposterior view must allow the distal humerus to be viewed from the front, which is difficult to achieve in a position that is pain-free for the patient. A lateral radiograph view is more easily achieved and is more commonly used for diagnosis (Fig. 14.1).The oblique view also details more of the injury and should be performed in every case (Lee and Lawton 2012; Ruchelsman et al. 2008; Yari et al. 2015). For better fracture line and fragment visualization, some authors prefer fluoroscopy in the operating room, with the arm in traction and the patient under general anesthesia in order to achieve a clear anteroposterior view (Bégué 2014).

An isolated capitellar fracture appears as half-moon-shaped fragment, so-called double-arc sign, on lateral radiographs. It is pathognomonic to a type-IV McKee fracture (McKee et al. 1996). In most cases it is difficult to clearly define coronal shear fractures on the basis of radiographs alone, so many authors recommended preoperative two- or three-dimensional computed tomography (CT) to better define these injuries (Ashwood et al. 2010; Singh et al. 2012; Watts et al. 2007).Two- and three-dimensional CT scan improves fracture pattern identification and visualization helping to establish a better preoperative injury description. Distal humerus CT can be

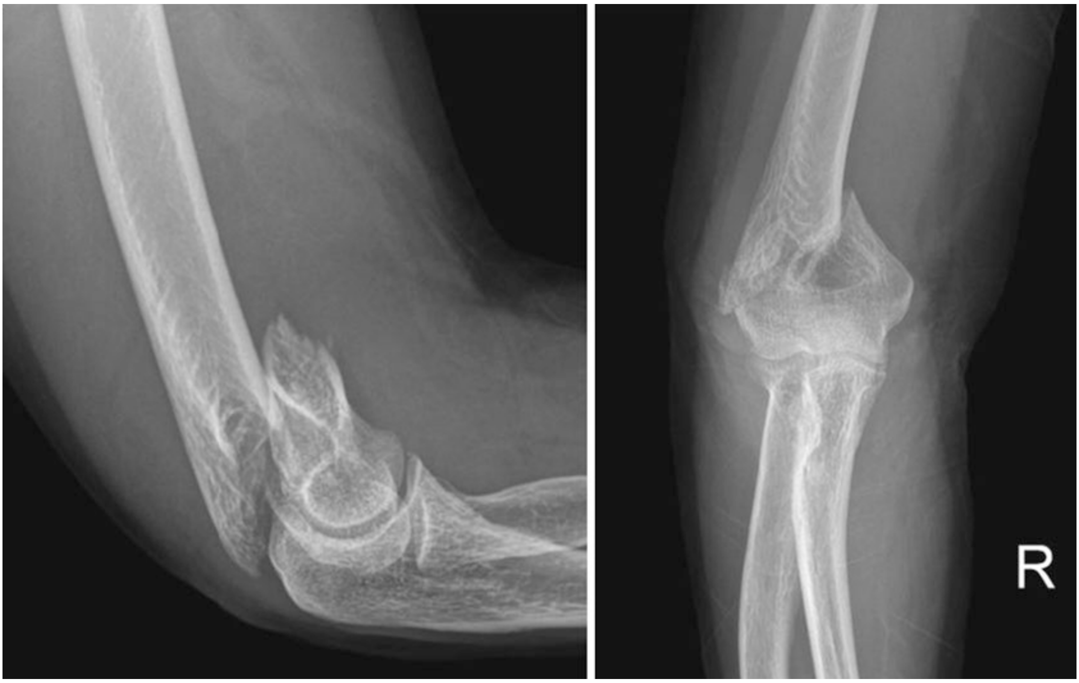


Fig. 14.1 Anteroposterior and lateral radiographic view of AO/OTA type A2 fracture

performed to further analyze the fracture pattern. Sagittal and coronal plane CT views and three-dimensional reconstruction provide more detailed information and are especially helpful in B3 and C3 fractures. Three-dimensional CT scans are useful when evaluating concomitant injuries, such as transcondylar or intercondylar distal humeral fractures. Concomitant capitellar fractures and radial head fractures may be missed on plain radiographs but more easily identified on a CT scan (Cheung 2007; Guitton et al. 2009; Ring et al. 2003).Three-dimensional reconstruction shows the shape and position of the bone fragments and is helpful in determining the appropriate surgical approach (Brouwer et al. 2012). CT imaging improves diagnostic precision and therefore can modify surgical decisions. Magnetic resonance imaging (MRI) is not usually indicated in distal humeral fractures, but may be used to evaluate soft tissue injury and may be helpful in evaluating cartilaginous injury (Sheehan et al. 2013). Doppler ultrasonography or angiography is useful to diagnose vascular injuries.

14.4 Treatment

The treatment of distal humeral fractures is challenging for orthopedic surgeons because the exposure of elbow may compromise neurovascular structures (Jung et al. 2016). Due to the complexity of the local anatomy and varying injury patterns, there is a high incidence of complications following surgery. Elbow stiffness and bony fragment devitalization are other problems with extended surgical exposures. The indications for elbow arthroscopy have expanded with increased experience in elbow arthroscopy and advances in instrumentation. The arthroscope is a promising tool for the diagnosis and treatment of distal humeral fractures. Arthroscopic-assisted surgery may be helpful in several types of distal humeral fractures including capitellar fractures, lateral condyle fractures, coronal shear fractures of the distal humerus, and pediatric distal humeral fractures (epicondylar, supracondylar, or unicondylar fractures) (Barnes et al. 2015; Holt et al. 2004; Tongel et al. 2012).

14.5 Operative Setup and Patient Positioning

Patients can be positioned either in prone, supine, or lateral decubitus positions, and a tourniquet is used. The elbow should be properly supported to enable easy instrumentation access, and the patient's position should also be easily convertible to an open procedure in case it is indicated. Lateral decubitus and prone positioning allows for easier access to the posterior elbow joint. The control of elbow flexion may help to obtain and maintain fracture reduction in the supine position. Supine positioning also has the advantage of easier conversion to open surgery if necessary.

In prone position, the arm is elevated on a padded block placed on an arm board at the patient's side. The elbow is flexed 90° to allow adequate elbow mobility and portal access. In supine an arm holder is used to secure the elbow and the forearm raising it so that the olecranon faces the surgeon. The lateral decubitus position requires an arm holder so that the triceps and olecranon is positioned facing upwards. Compression of neurovascular structures in the arm and axilla should be avoided by using a soft bolster with a padded axillary roll. A compression wrap should be used at the forearm and hand to minimize swelling and fluid extravasation.

14.6 Portal Placement and Surgical Approach

Portal placement is determined with consideration for the safety of adjacent neurovascular structures, musculotendinous anatomy, and fracture location. Bone landmarks, neural structures, and potential portal entries are marked on the skin and ulnar nerve location, and mobility of the ulnar nerve is carefully noted. Medial portal placement may increase ulnar nerve injury risk if its course is not well determined.

To minimize neurovascular injury risk, portals should be created with a fully distended joint and 90° of elbow flexion. The soft spot portal or posterocentral portal can be used for joint distention. The normal fluid capacity of the elbow joint is 25 mL (O'Driscoll et al. 1990). Fracture hematoma may cause joint distention that provides adequate intracapsular pressure before portal placement. High pressures may lead to post-fracture compartment syndrome. Surgeons who perform the arthroscopic procedure should be cautious of the altered anatomy associated with fracture displacement, soft tissue swelling, and injured ligamentous structures. Use of the midlateral (soft spot portal), proximal lateral, trans-triceps, distal posterolateral, and anteromedial portals are the safest options (Dodson et al. 2008).

The skin is incised with a sharp scalpel blade, and the arthroscopic cannula or obturator is used for blunt separations. A standard 4-mm 30° arthroscope is used for most procedures, but a 70° scope may be helpful for capitellar fractures of the humerus. Two or three portals can be created as needed with one for visualization and the others for instrumentation. Arthroscopic elbow portals that can be used for treating distal humeral fractures include the anterolateral and anteromedial portals, soft spot portal, proximal anterolateral and proximal anteromedial portals, anterosuperior portal, and posterocentral and posterolateral portals.

Anterolateral

- Located 3 cm distal and 1 cm anterior to the lateral epicondyle.
- Radial nerve, posterior interosseous nerve, and lateral antebrachial cutaneous nerve are at risk.

Anteromedial

- Located 2 cm distal and 2 cm anterior to the medial epicondyle.
- Medial antebrachial cutaneous nerve is at risk.
- Medial gutter can be observed.

Soft spot

- Located in the triangle between the olecranon tip, radial head, and lateral epicondyle.
- Radiocapitellar and lateral ulnohumeral joints are at risk.
- Posterolateral portion of the elbow can be observed.

Proximal anterolateral

- Located 2 cm proximal and 1 cm anterior to the lateral epicondyle.
- Radial nerve is at risk.
- Anterior radio-humeral and ulnohumeral joints and the anterior capsular margin can be observed.

Proximal anteromedial

- Prone or lateral decubitus position.
- Located 2 cm proximal to the medial epicondyle and just anterior to the medial intermuscular septum.
- Ulnar nerve, medial antebrachial cutaneous nerve, median nerve, and brachial artery are at risk.
- Trochlea, coronoid process, medial condyle, radial head, and capitellum can be observed.

Anterosuperior lateral

- Located 2 cm anterior to the lateral epicondyle.
- Posterior interosseous and lateral antebrachial cutaneous nerves are at risk.
- Medial portion of the anterior elbow, coronoid process, and coronoid fossa, and anterior portion of the radiocapitellar can be observed.

Posterocentral

- Located 3 cm proximal to the olecranon tip and midline through triceps muscle.
- Triceps tendon is at risk.
- Olecranon, olecranon fossa, and medial and lateral gutter can be observed.

Posterolateral

- Located 3 cm proximal to the olecranon and just lateral to the triceps tendon.
- Triceps tendon and ulnohumeral joint are at risk.
- Olecranon, olecranon fossa, medial and lateral gutter, and posterior radiocapitellar joint can be observed.

14.7 Surgery

1. **Capitellar Fractures**

   Capitellar fractures represent less than 1% of all elbow fractures. Capitellar fractures are divided into three types. Type I is the Hahn-Steinthal fragment which is a large osteocartilaginous fragment. Type II is the Kocher-Lorenz fragment which is a rim of articular cartilage without underlying bone. The fragment is usually free of soft tissue attachments and characteristically displaces proximally. Type III fractures are comminuted fractures.

An arthroscopic-assisted technique can be used to treat type I and II capitellar fractures. Standard anteromedial, anterolateral, and posterolateral portals are used for visualization, and proximal anteromedial and posterior portals are used for visualization and fracture debridement. A proximal anterolateral portal can be used for fragment manipulation to aid reduction. The fragment is reduced to its anatomic position using gentle forearm traction, elbow extension, and arthroscopic manipulation. The elbow is then hyper-flexed and the fragment is locked by the radial head. While reduction is maintained, Kirshner (K) wires are used for temporary fixation. Final fracture fixation can be achieved by cannulated screws, headless compression screws, bioabsorbable pins, or transosseous sutures. Arthroscopic debridement and excision via standard anteromedial and anterolateral portals can be performed for type III fractures (Barnes et al. 2015; Holt et al. 2004; Tongel et al. 2012).

Sequel of a coronal shear fracture also can be seen. A 28-year-old male patient was admitted with left elbow pain and limitation of joint movement following a conservative treatment of elbow trauma. Six months ago he had an elbow trauma and was treated conservatively with long arm casting. His elbow flexion was limited at 90 degrees. A bony block could be felt by physical examination of elbow flexion. Figure 14.2 shows preoperative X-rays and CT films of malunion of trochlear fracture with articular surface which causes flexion blockage. This patient was treated with arthroscopic examination, joint debridement, and removal of prominent articular surface with a burr. Figure 14.3 shows arthroscopic appearance of trochlear bony prominence with articular cartilage and its bone

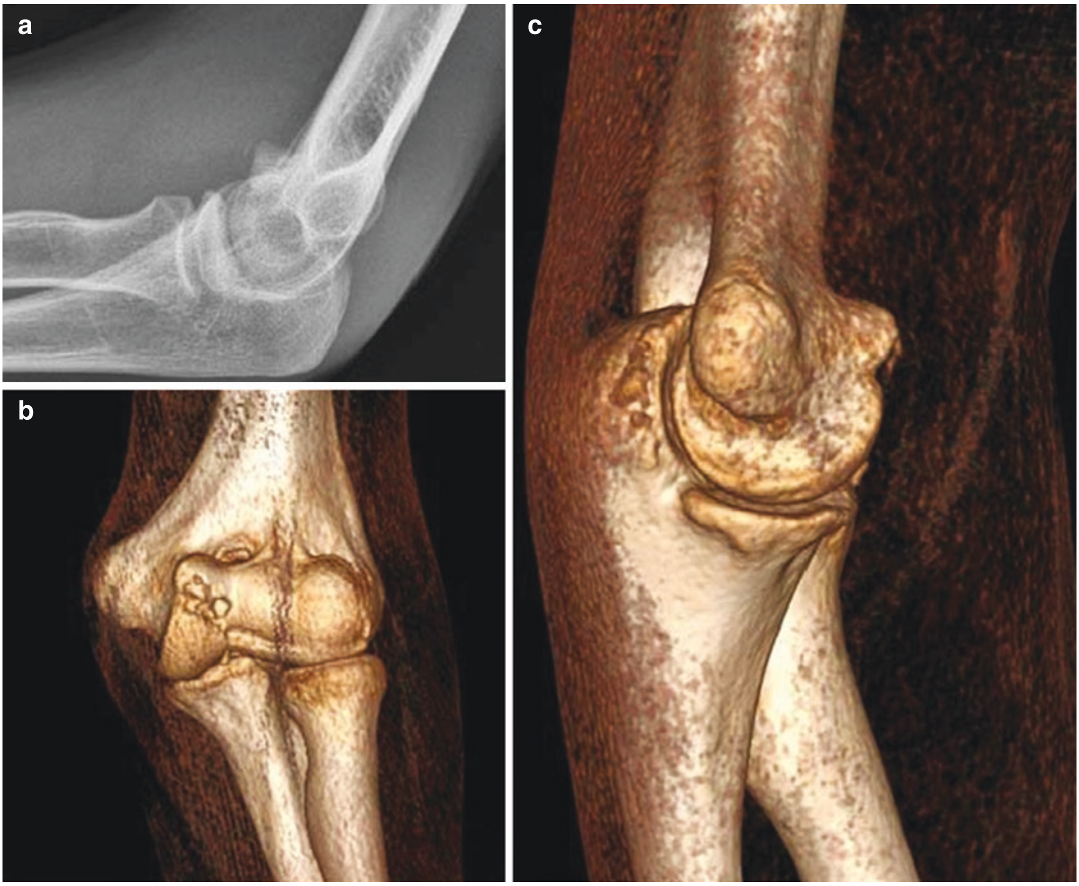


Fig. 14.2 A 28-year-old patient with sequelae of coronal shear fracture of coronoid and trochlea. (**a**) Lateral radiography of semi-extended elbow shows a bony prominence at the anterior part of the distal humerus which causes a bony blockage of elbow flexion. (**b**) Anteroposterior view of 3D reconstructed elbow CT shows superior displacement of trochlear fragment causing malunion. (**c**) Lateral view of 3D reconstructed elbow CT shows a bony prominence just superior of articular surface

shaving with a burr. Three weeks following removal of bony blockage, elbow range of motion increased to 110 °.

2. Pediatric Epicondylar, Supracondylar, and Unicondylar Fractures

   Displaced medial epicondylar fractures may lead to elbow instability, and arthroscopic-assisted surgery can be used in the treatment of avulsion fractures of medial apophysis. The arthroscope may be used in the treatment of supracondylar fractures with minimal comminution. Anatomic reduction is confirmed under direct arthroscopic view, and K-wires, a probe, or an elevator may be used as reduction tools. K-wires or cannulated screws are used for fixation. Fluoroscopic intraoperative imaging is extremely useful, particularly in the vicinity of the olecranon fossa. Posterior portals can be used to confirm fracture reduction and to evaluate the olecranon fossa. Pediatric unicondylar fractures with a small minimally displaced fragment (Milch type I) are amenable to arthroscopic-assisted surgery. Conservative treatment and open surgery are the other treatment options. Arthroscopic-assisted fixation offers a notable alternative concerning the potential disadvantages of nonoperative treatment (immobilization, late fracture displacement, and joint incongruity) and open

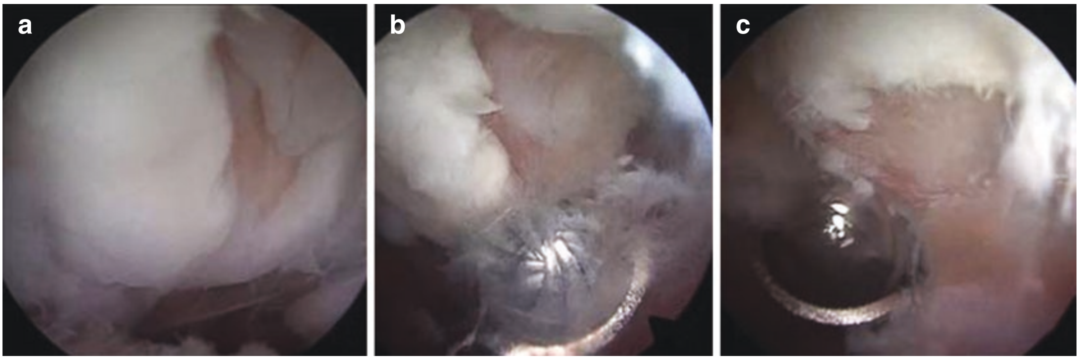


Fig. 14.3 (**a**) Arthroscopic appearance of malunion part of trochlear articular surface and bony prominence. (**b**) Bony prominence with articular surface removed with a burr. (**c**) Appearance of anterior part of distal humerus after removal of bony prominence

surgery (additional soft tissue damage) (Holt et al. 2004; Mehme and Jupiter 1992; Tongel et al. 2012).

Standard anteromedial and anterolateral portals are created. Closed reduction of the fracture is performed using manual pressure and confirmed under arthroscopic visualization. K-wires or cannulated screws are used for fixation. Fluoroscopic control is mandatory to confirm position, length, and trajectory of the K-wires or cannulated screws.

3. Intercondylar Fractures

   Arthroscopic-assisted fixation can be used in type C1 intercondylar fractures. Arthroscopic visualization of the anterior and posterior elbow and viewing the articular surface helps the surgeon confirm anatomic reduction. Cannulated screws can be used for fracture fixation. Careful patient selection is important. This technique is suitable for single-column fractures in patients with good bone quality and lower physical function expectations (Holt et al. 2004).

   Advantages

- Direct fracture and articular surface visualization
- Evaluation of associated injuries
- Better radiolucent pediatric fracture assessment
- Anatomic reduction confirmation
- Minimal soft tissue disruption, better wound healing, lower risk of infection, and less postoperative pain
- Preserved collateral ligaments and blood supply (reduced risk of osteonecrosis)
- Early joint rehabilitation and reduced risk of elbow stiffness (Barnes et al. 2015; Hardy et al. 2002; Holt et al. 2004; Mehme and Jupiter 1992; Mitani et al. 2009; Tongel et al. 2012)

   Disadvantages and Complications

- Long learning curve and challenging technique
- Major nerve injury, septic arthritis, transient nerve palsy
- Inadequate reduction or loss of fixation (Barnes et al. 2015; Holt et al. 2004; Tongel et al. 2012)

14.8 Conclusion

Although a number of treatment options have been reported, open reduction and internal fixation is the treatment of choice in most distal humeral fractures. Surgical treatment of distal humeral fractures is usually associated with problems such as intra-articular comminuted fragments, an extensive surgical approach, and close proximity to neurovascular structures. Adequate articular surface fixation is essential to achieve satisfactory clinical results. Arthroscopic-assisted surgery may be helpful in several types of distal humeral fractures including capitellar fractures, lateral condyle fractures, coronal shear fractures of the coronoid, and pediatric distal humeral fractures (epicondylar, supracondylar, or unicondylar fractures). Direct articular surface visualization, more effective evaluation of possible associated pathologies, and better wound healing are major advantages of arthroscopic-assisted internal fixation. Technical difficulties specific to elbow arthroscopy and its long learning curve, however, are the challenging part of arthroscopic-assisted internal fixation. Proper selection of patients based on fracture type appropriateness for arthroscopic-assisted surgery is critical for the effective distal intra-articular humeral fracture treatment.

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15

Radial Head and Olecranon Process Fractures

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15.1 Epidemiology

Fractures of the radial head are the most common fractures in the elbow (Kaas et al. 2010a) with an estimated incidence of 3 per 10,000 inhabitants per year. The average age of patients who experience a radial head fracture is between 45 and 48 years (Duckworth et al. 2012c; Kaas et al. 2010a; van Riet et al. 2005). Male-female ratios vary between 1:1, 2:3, and 3:2 (Duckworth et al. 2012b; Kaas et al. 2010b; Jackson and Steinmann 2007; Mason 1954). Female patients tend to be relatively older compared to male patients (Kaas et al. 2010b; van Riet et al. 2005). However the number of female patients with a radial head fracture is significantly larger than the number of male patients after 50 years of age (Kaas et al. 2010a). This can be explained by a correlation with the higher incidence of osteoporosis in female patients above 50 years of age (Kaas et al. 2012). Olecranon process fractures represent approximately 0.9% of all fractures, 18% of all proximal forearm fractures, and 10% of all upper extremity fractures and have an overall incidence of 12 per 100,000 people (Rouleau et al. 2013). The most common olecranon process fracture injury mechanism is a fall from standing height. Concomittant injuries such as radial head and neck fractures are commonly observed. The mean age of all patients who sustain olecranon process fractures is between 50 and 60 years. The most commonly observed elbow fracture is a simple, displaced olecranon process fracture representing 73.5% of all such injuries (Duckworth et al. 2012a, b, c).

15.2 Diagnosis

A detailed history and examination can provide information on the probability of associated injuries. A simple fall is the most common injury mechanism (73%) especially among patients with osteoporosis (Duckworth et al. 2012b). Joint stability testing such as elbow varus/valgus stress tests are often difficult to perform in acute cases due to patient pain levels. On physical examination, tenderness and ecchymosis over the medial or lateral humeral epicondyles may indicate the presence of additional ligamentous injury, whereas pain in the wrist or forearm should raise the suspicion of an Essex-Lopresti lesion. Aspiration of the intra-articular hemarthrosis with local anesthetic injection can facilitate the clinical examination (Yoon et al. 2012). The presence of elbow pain, swelling, and an inability to extend the elbow against gravity are common findings for a patient with an olecranon process fracture. Physical

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examination of the involved upper extremity and adjacent joints should include careful observation, palpation, and complete neurovascular examination. A palpable defect may be appreciated if there is substantial fracture displacement. It is extremely important to closely examine the skin for any evidence of an open ulna fracture (Wiegand et al. 2012).

15.3 Imaging

Both anteroposterior (AP) and lateral radiographs should be obtained to diagnose radial head fractures (Grundy et al. 1985; Hall-Craggs et al. 1985; Horsfield and Siegerist 2005; Manns and Lee 1990; Page 1986; Sartoris and Resnick 1988). If there is an obvious fat-pad sign without fracture observed in standard radiographs, an additional Greenspan or radiocapitellar view should be taken (Hall-Craggs et al. 1985). In patients with a positive fat-pad sign but no fracture evidence on initial radiography, follow-up radiography 7–14 days later may reveal radial head or neck fractures (Morewood 1987).

Intra-articular fragments or impacted fractures can be identified much better on CT scans (Sormaala et al. 2014). MRI scans are helpful for evaluating soft tissue injuries, enabling good visualization of tendon and ligament injuries, as well as nondisplaced fracture lines (Kaas et al. 2010a; Timmerman et al. 1994). Similar with radial head imaging, the evaluation of proximal ulnar fractures should include standard anteroposterior and lateral elbow radiographs supplemented with a radiocapitellar view as needed (Ring 2010). Recent improvements in imaging techniques and availability of 3-dimensional (3D) computed tomographic (CT) reconstructions have led some investigators to recommend greater use of more advanced imaging for patients who possess Type II: Marginal sector fractures with displacement and Type III: Comminuted fracture of the radial head (Johnston 1962).

15.4 Classification

The Mason classification is the accepted classification system for radial head fractures (Mason 1954). This classification consists of three types: Type 1, undisplaced fractures; Type 2, displaced fractures; and Type 3, fractures that are displaced with comminution. A fourth type, representing a radial head fracture accompanied by elbow dislocation, was added by Johnston (1962). Furthermore, Broberg and Morrey (1987) added a metric definition of displacement (<2 mm or >2 mm) and an area of involvement of the articular surface (>30%) to differentiate between Mason Type I and Type II fractures. The Mason classification however has shown low interobserver and intraobserver reliability (Guitton and Ring 2011; Sheps et al. 2009). The use of 3-dimensional CT imaging significantly improves the interobserver reliability compared with 2-dimensional imaging. However, only moderate agreement exists regarding the necessity for this imaging method (Guitton and Ring 2011).

Several different classification systems have been described for olecranon process fractures (Bernstein et al. 1997; Schatzker 1996), but no particular system has gained widespread acceptance. None of the classification systems have proven to be more reliable than the others. The challenges of testing the reliability of classification systems have been discussed in the literature (Audigé et al. 2004). The Mayo classification (Bernstein et al. 1997) which is based on displacement and ulnohumeral joint stability could be used to guide treatment: Type I, nondisplaced fractures, treated nonoperatively; Type II, displaced, stable fractures that require operative fixation; and Type III, displaced, unstable fractures that require operative fixation. The Schatzker classification (Schatzker 1996) subdivides fractures based on their pattern: transverse, transverse-impacted, oblique, comminuted with associated injuries, oblique-distal, and fracture-dislocation. The AO classification (Muller et al. 1991) of proximal radius and ulna fractures tends to be used more frequently for research purposes. With this classification system, Type A fractures represent extra-articular metaphyseal fractures, Type B fractures represent intra-articular fractures of either the proximal radius or ulna, and Type C fractures represent intra-articular fractures of the radial head and olecranon process.

15.5 Treatment

15.5.1 Radial Head Fractures

Nondisplaced, stable, and minimally displaced partial articular fractures of the radial head are treated nonoperatively (Boulas and Morrey 1998; Unsworth-White et al. 1994). Successful, long-term clinical outcomes (Akesson et al. 2006; Herbertsson et al. 2004) have encouraged conservative treatment and use of early active motion for two-part fractures of the radial head associated with 2–5 mm of displacement when the elbow is stable. Hematoma aspiration and lidocaine injection can be helpful to physical examination if a mechanical block is suspected. Unstable partial articular fractures are defined by gross displacement, metaphyseal bone loss, radiocapitellar articular incongruency, malalignment and impaction, restricted elbow and/or forearm motion, and the presence of associated elbow or forearm fracture-dislocation patterns (Ring et al. 2002). Open reduction and internal fixation along with soft tissue repair is indicated for these fractures.

The aim of open reduction and internal fixation is to provide stable articular surface fixation and articular congruency restoration. Small, cannulated headless compression screws implanted beneath the articular surface are often used for unstable fractures (Esser et al. 1995; King et al. 1991; Khalfayan et al. 1992; Lindenhovius et al. 2009; Pearce and Gallannaugh 1996; Rochwerger et al. 1996). However, other surgical options such as radial head excision or prosthetic replacement might be indicated in comminuted and unstable fracture cases.

If stable fixation can be achieved, open reduction and internal fixation of multi-fragment articular surface radial head fractures is indicated in younger patients. This allows for restoration of the lateral column and early motion. In the case of a highly comminuted fracture in which stable fixation cannot be achieved, prosthetic replacement is preferred. Radial head arthroplasty may offer more predictable results for unstable and complex, complete articular fractures (Bain et al. 2005; Doornberg et al. 2007; Dotzis et al. 2006; Grewal et al. 2006; Johnson et al. 2005; Moro et al. 2001; Popovic et al. 2000; Ruan et al. 2009; Smets et al. 2000). Radial head arthroplasty aims to help stabilize an elbow with traumatic instability (Doornberg et al. 2007) when stable fixation of a multifragmentary articular fracture of the radial head is not possible (King et al. 1991; Ring et al. 2002).

15.6 Complex Elbow and Forearm Injuries

Acute radial head excision is rarely performed in Mason Type 2 (unstable, displaced partial articular) and Mason Type 3 (complete articular fractures of the radial head and neck) associated with complex periarticular fracture dislocations about the elbow and forearm (Davidson et al. 1993; Dubberley et al. 2006). Open reduction and internal fixation yields superior results to radial head excision for the treatment of complex elbow fracture-dislocations (Ikeda et al. 2005; Lindenhovius et al. 2007).

15.7 Olecranon Process Fractures

Non- or minimally displaced (<2 mm) olecranon process fractures (Mayo Types IA and IB) can be managed nonoperatively (Fig. 15.1).

Elbow and forearm immobilization is provided using a long arm cast with the elbow in 90° flexion for 3–4 weeks. This is followed by protected elbow and forearm range of motion exercises. A follow-up radiograph should be obtained within 5–7 days following cast application to ensure that fracture displacement has not occurred (Veillette and Steinmann 2008).

Fig. 15.1 Olecranon fracture with significant hemarthrosis

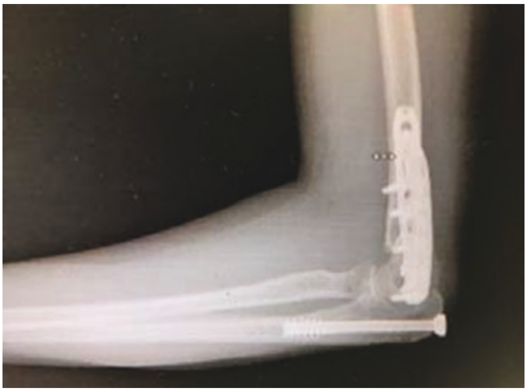

Fig. 15.2 Distal humerus fracture open reduction internal fixation, olecranon process osteotomy using a cannulated screw

15.8 Tension Band Wire/Cannulated Screw

Displaced olecranon process fractures require operative treatment to restore elbow extension, joint congruity, and elbow stability. Transverse fractures without comminution (Mayo Type IIA) can be managed with tension band wiring or cannulated screw fixation (Fig. 15.2).

15.9 Plating

Plate and screw fixation has several advantages. The plate allows improved contouring and can be appropriately placed on the dorsal tension surface of the proximal ulna around the tip of the olecranon process to help hold the proximal fragment when poor bone quality limits adequate screw purchase (McKee et al. 1995; Simpson et al. 1996). A higher incidence of prominent, painful hardware has been reported after tension band wiring than compression plating (Hume and Wiss 1992; Wolfgang et al. 1987).

15.10 Arthroscopic Radial Head Fixation

Rolla and colleagues fixed displaced Type 2 fractures using a single cannulated screw, placed from an anterolateral portal perpendicular to the fracture line. Their short-term results yielded no complications, and all patients returned to premorbid activity within 6 months (Rolla et al. 2006). Excision is indicated for comminuted fractures or for small fragments less than 25% of the articular surface, in low-demand patients with no concomitant elbow or forearm disorder (Wijeratna et al. 2012).

15.11 Conclusion

Fractures of the radial head and olecranon process present significant surgical challenges. Fractures of the radial head are the most common fractures in the elbow with an estimated incidence of 3 per 10,000 inhabitants per year. A simple fall is the most common mechanism of injury especially in patients with osteoporosis. Both anteroposterior and lateral radiographs should be obtained to diagnose radial head and olecranon process fractures. Intra-articular fragments or impacted fractures can be identified much better on CT scans. MRI scans are helpful for evaluating soft tissue injuries. The Mason classification (1954) is the accepted classification system for fractures of the radial head: Type 1, undisplaced fractures; Type 2, displaced fractures; and Type 3, fractures that are displaced with comminution. A fourth type representing a radial head fracture accompanied by elbow dislocation was added by Johnston (1962). Nondisplaced and stable, minimally displaced partial articular fractures of the radial head are treated nonoperatively. Open reduction and internal fixation along with soft tissue repair is indicated for unstable fractures. Other surgical options such as radial head excision or prosthetic replacement might be indicated in comminuted and unstable fracture cases.

Olecranon process fractures are among the most common fractures in the elbow. Olecranon process fractures have an overall incidence of 12 per 100,000 people. The presence of elbow pain, swelling, and inability to extend the elbow against gravity are the common findings for a patient with an olecranon process fracture. Several different classification systems have been described for olecranon process fractures, but no particular system has gained widespread acceptance. The Mayo classification (Bernstein et al.

1997) which is based on displacement and ulnohumeral joint stability could be used to guide treatment: Type I, nondisplaced fractures, treated nonoperatively; Type II, displaced, stable fractures that require operative fixation, tension band wire, and plating; and Type III, displaced, unstable fractures that require operative fixation, tension band wire, and plating.

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16

Shoulder Rehabilitation After Minimal Invasive Surgery Around Shoulder Joint

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16.1 Rehabilitation After Proximal Humerus Fracture Surgery

Proximal humerus fractures represent one of the most common reasons for minimally invasive shoulder surgery. A fall (often low energy) is the most common mechanism. The rehabilitation approach that is used for patients following proximal humerus fractures differs depending on fracture type, pattern, and surgical approach (Brunner et al. 2009).

The medical literature suggests that an arm sling should be for approximately 3 weeks following proximal humerus fracture surgery to immobilize the shoulder and protect the healing fracture site. The arm sling is removed periodically during each day to allow for personal needs such as bathing and to enable therapeutic exercise performance, particularly at the wrist and elbow joints. Except for personal needs and therapeutic exercises, arm sling use is recommended during the day over the initial 4–6 weeks following surgery. During the night, an arm sling and swath or a cooling and compression rotator cuff repair-type sling is recommended.

In a systematic review of studies that used locking plate fixation of proximal humerus fractures, Sproul et al. (2011) reported that early controlled passive shoulder mobilization performed within pain-free limits was recommended. Based on this report, the following therapeutic exercise progression is recommended:

Stage I: During shoulder immobilization, the therapeutic exercise program used over the initial 3 weeks post-surgery consists primarily of passive shoulder range of motion movements performed within pain-free limits, as well as active handwrist and elbow exercises. All therapeutic exercises should be performed under the supervision of a physiotherapist. Passive shoulder mobility exercises should be initiated with progressive flexion, external rotation, and internal rotation exercises which should be performed up to four times daily.

Stage II: Active-assisted shoulder exercises are initiated after the third postsurgical week and are continued for approximately 4–6 weeks. Active external rotation and abduction should be restricted to 20° and 90°, respectively, over this time period. At 6–8 weeks post-surgery, with radiographic evidence of appropriate healing, the implant used during the first surgery should be removed.

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Stage III: Isotonic strengthening occurs from week 9 to week 12 post-surgery. At 12 weeks, terminal active shoulder range of motion and terminal joint stretch restrictions are removed. At approximately 16 weeks post-surgery, patients are generally allowed to return to unrestricted sports activities as tolerated (Brunner et al. 2010, 2012; Kirkley et al. 2005).

16.2 Rehabilitation After Acromioclavicular Joint Dislocation Surgery

Acromioclavicular joint dislocation injuries are associated with falling directly on the acromion process of the shoulder, contact sports injuries, and motor vehicle accidents. Rockwood and Green (1996) classified acromioclavicular joint dislocations into six types (Gorbaty et al. 2017). While types I–III are generally managed nonoperatively with physiotherapy referral, types IV–VI necessitate operative management (Choi et al. 2008; Fukuda et al. 1986; Guy et al. 1998; Lee et al. 2003).

As with proximal humerus fracture postsurgical management, an arm sling is recommended to immobilize the shoulder during the day over the initial 6 weeks following acromioclavicular joint surgery. On the second postoperative day, passive- and active-assisted shoulder flexion and abduction movements are initiated with restrictions to pain-free limits and 90°. Passive- and active-assisted shoulder external and internal rotation movements are also initiated, with the shoulder maintained in an adducted position with similar restrictions to pain-free limits and 30°.

Active shoulder mobility exercises are initiated at approximately 4 weeks post-surgery. Arm sling use is discontinued at approximately 6 weeks post-surgery. At this time both passive and active shoulder flexion and extension movements should be at or close to full range. Progressive resistance exercises can also be started during this time period; however, subjectively heavy objects should not be lifted and carried over the initial 3 months post-surgery (Choi et al. 2008; Fukuda et al. 1986; Guy et al. 1998; Lee et al. 2003; Pabia et al. 2011). In general, patients who undergo rehabilitation following minimally invasive shoulder surgery should progress through the following three phases:

16.2.1 Phase I: 0–3 Weeks Post-surgery

The goals for this phase include achievement of soft tissue healing, preservation of shoulder joint integrity, progressively increasing passive shoulder joint mobility and active joint mobility, and strengthening of the elbow, wrist, and hand musculature. Within this context, this period also focused on reducing shoulder pain and inflammation and decreasing upper extremity neuromuscular inhibition. Although therapeutic exercises at the shoulder are limited to passive mobility during this phase, active mobility and strengthening throughout the more distal joints are recommended to maintain upper extremity neuromuscular function. Some examples of therapeutic exercises that should be performed during this phase include:

Wrist Flexion-Extension Active Mobility and Stretching: With the shoulder adducted and the elbow extended, the patient actively flexes and extends their wrist. When terminal active range of motion is achieved, the other hand is used to provide a slight passive stretch. This stretch is held for 20 s and repeated with three repetitions. Active wrist flexion-extension is performed for 20 repetitions, 1–2 times daily.

Wrist Flexor Strengthening: The elbow is positioned on the table in extension position, with the palm facing up. After successful, full range of motion is achieved against gravity, resistance is progressively increased within patient tolerance for 1–2 sets of 10–15 repetitions, 1–2 times daily (Fig. 16.1).

Wrist Extension: The elbow is positioned on the table or bed in extension position, with the palm facing down. After successful, full range of motion is achieved against gravity, resistance is progressively increased within patient tolerance for 1–2 sets of 10–15 repetitions, 1–2 times daily (Fig. 16.2).

Fig. 16.1 Wrist flexion against resistive band

Fig. 16.2 Wrist extension against resistive band

Passive Shoulder Mobility Exercises: With the patient in supine position, passive shoulder mobility exercises including progressive flexion, external rotation, and internal rotation within pain-free limits, gradually increasing to chest level, should be performed under the supervision of a physiotherapist. These movements should be repeated for 10–15 repetitions, 3–4 times daily.

Exercises Performed in the Scapular Plane: Since they are essential to shoulder joint health and function, scapular mobility and isometric strengthening therapeutic exercises should be performed for 10–15 repetitions, 1–2 times daily, holding each isometric muscle activation for 6 s (Fig. 16.3a, b). Isometric shoulder extensor (Fig. 16.4) and internal rotator strengthening with a towel rolled placed between the adducted shoulder and the trunk (Fig. 16.5) should be performed for 10–15 repetitions, 1–2 times daily, holding each isometric muscle activation for 6 s. These exercises should be continued through all rehabilitation phases with the addition of progressive shoulder abduction and internal-external rotation (Fig. 16.6a–c) (Camcı et al. 2013).

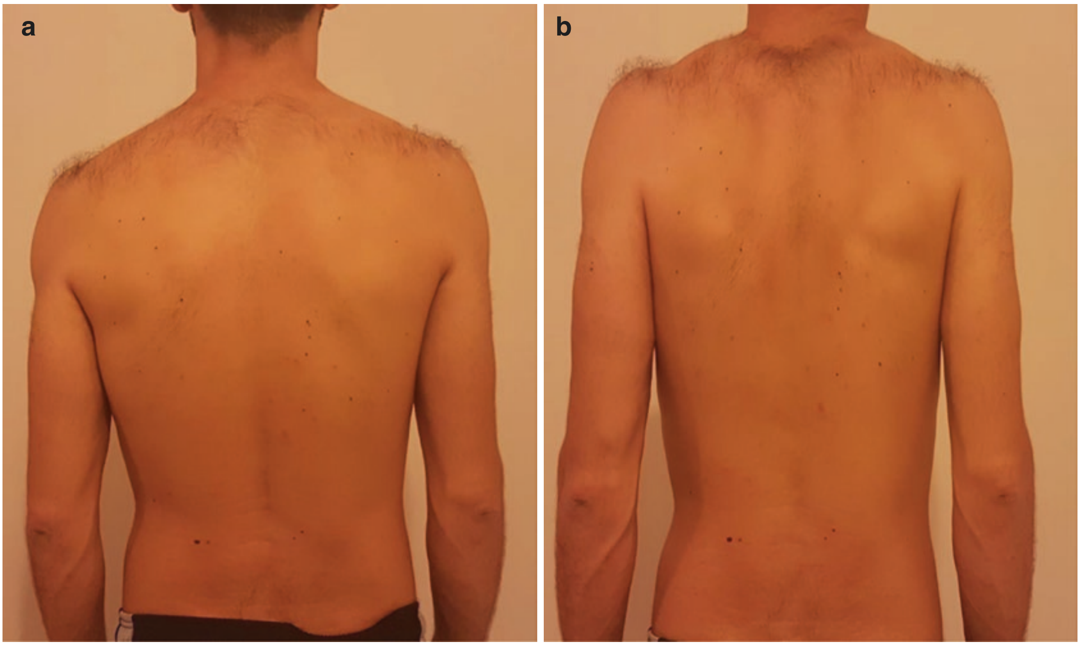

Fig. 16.3 (**a**) Normal standing posture. (**b**) Scapular retraction

Fig. 16.4 Shoulder isometric extension

Fig. 16.5 Shoulder isometric internal rotation

Fig. 16.6 (**a**) Supine shoulder flexion with wand. (**b**) Supine shoulder flexion to chest level. (**c**) Supine progressive shoulder abduction-adduction with wand

16.2.2 Phase II: 4–6 Weeks Post-surgery

The goals of this phase are to improve upper extremity strength, proprioception, and neuromuscular control of the shoulder joint complex. Some examples of therapeutic exercises that are performed during this phase include:

Biceps-Triceps Curls: The biceps and triceps brachii are important stabilizers (Andrews et al. 1993, 2012; Ellenbecker and Davies 2001). Therefore, biceps (Fig. 16.7)-triceps (Fig. 16.8) curls are performed for 1–2 sets of 10–15 repetitions using a resistive band taking the elbow joint through full range of motion, including controlled eccentric neuromuscular activation.

Scapular Retraction in Prone Position: Scapular retraction exercises with progressive shoulder external rotation performed in prone should also be performed for 1–2 sets of 10–15 repetitions, 1–2 times daily (Fig. 16.9).

Scapular Plane Shoulder Elevation: Internal Rotation-External Rotation: Toward the end of this phase, shoulder external rotation exercises are started with resistive bands. At this time, initially active and then progressive resistance scapular plane shoulder elevation combined with internal and external rotation movements is performed for 1–2 sets of 10–15 repetitions, 1–2 times daily (Figs. 16.10a, b and 16.11).

Fig. 16.7 Biceps curl with resistive band

Fig. 16.8 Triceps curl with resistive band

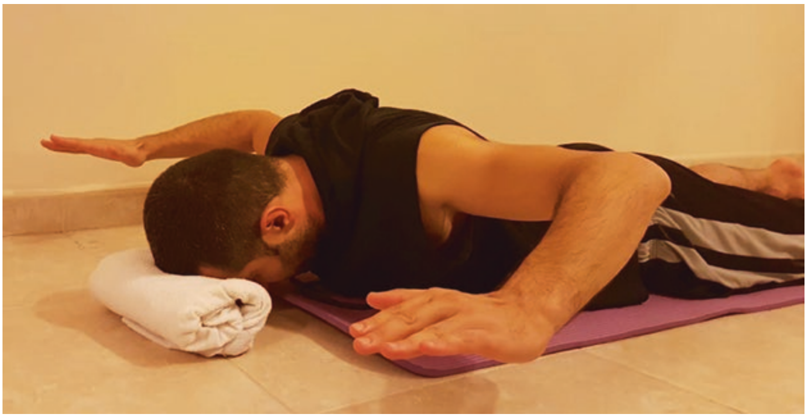

Fig. 16.9 Scapular retraction and progressive shoulder external rotation in prone position

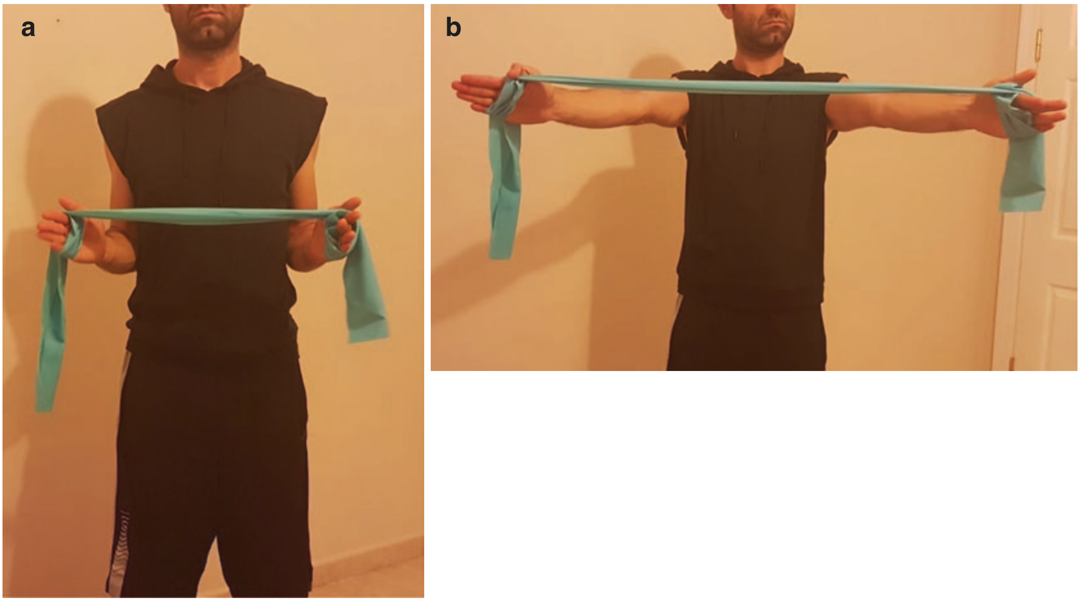

Fig. 16.10 (**a**) Standing, bilateral shoulder external rotation with resistive band. (**b**) Standing, shoulder horizontal abduction against resistive band

16.2.3 Phase III: 6–8 Weeks Post-surgery

The goal of this phase is to gradually integrate sports or work-specific therapeutic exercises into the rehabilitation plan. By the end of this phase, full shoulder mobility and strength should be achieved, and preinjury functionality should be restored. Examples of therapeutic exercises performed during this phase include:

Proprioceptive Neuromuscular Facilitation (PNF) Pattern Shoulder Elevation: Progressing from active against gravity to resistive band use (Fig. 16.12).

Proprioceptive Perturbation Training: Rhythmic stabilization exercises begin with the physiotherapist applying sudden, unexpected loads to the upper extremity with the patient in a supine position. This progresses to front and lateral single arm stabilization of a Swiss ball

Fig. 16.11 Resistive shoulder elevation

Fig. 16.12 Multi-planar shoulder elevation in diagonal 2 (D2) PNF pattern

against a wall with the shoulder in assorted elevation and rotation positions. The goal of this phase is to facilitate neuromuscular co-activation efficiency to improve dynamic shoulder joint stability, endurance, and coordination (Wilk et al. 2011). Examples of therapeutic exercises performed during this phase include quadruped weight-bearing scapular retraction-protraction on a Swiss ball (Fig. 16.13a, b), bilateral kneeling push-up and push-up plus movements on a Swiss ball (Fig. 16.14), standing wall push-up exercise (Fig. 16.15), and standing single arm lateral wall push-up with a Swiss ball (Fig. 16.16).

Further strengthening can be achieved by including more conventional strength training exercises such as barbell bench presses and rows. Plyometric two-handed medicine ball chest passes, side throws, or overhead throws can be added during this period to translate shoulder strength into more functional, whole-body movements.

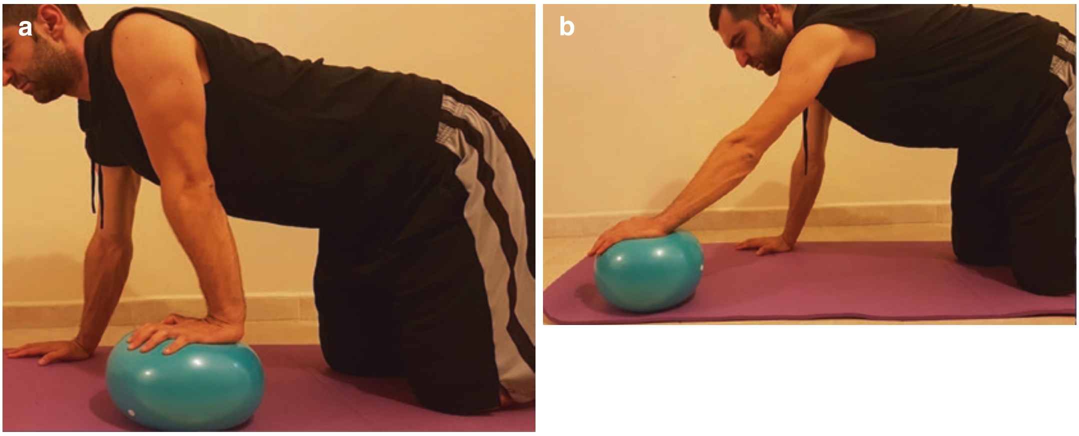

Fig. 16.13 (**a**) Quadruped weight-bearing scapular retraction-protraction on a Swiss ball. (**b**) Quadruped weight-bearing scapular retraction-protraction on a Swiss ball with the shoulder flexed past 90°

Fig. 16.14 Bilateral kneeling push-up and push-up plus movements on a Swiss ball

Fig. 16.15 Standing wall push-up exercise

Fig. 16.16 Side wall push-up

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17

Rehabilitation After Minimally Invasive Fixation of Elbow Fractures

Sven Reuter, Andreas B. Imhoff,
and Andreas Lenich

17.1 General Rehabilitation Guidelines

The goal of rehabilitation after minimally invasive fixation of elbow fractures is to restore full range of motion and regain pain-free elbow function. Therefore, it is necessary to understand the surgical technique and biomechanical stresses that occur with exercises during the rehabilitation. Treatment of the patient must be interdisciplinary by the rehabilitation specialist and the surgeon.

Athletes consider regaining full elbow function and their previous level of performance as most important outcome indicators after surgical treatment. Hence the rehabilitation program is progressive and is carefully planned to address all aspects in a multimodal approach. Not only the recovery of mobility, strength, and flexibility is crucial, after elbow fracture fixation, but also the rehabilitation must ensure efficient neuromuscular control of the elbow for work-related and sport-specific demands. The primary aim of the rehabilitation approach is to assess and treat deficits of the entire body. Deficits of the whole kinetic chain must be addressed during the rehabilitation process. The proximal links of the upper extremity and core stability must be integrated. Range of motion, function, muscle strength, endurance, and neuromuscular control are the primary focus points in all phases of rehabilitation.

17.2 Phases of the Rehabilitation Program

The rehabilitation program may be divided into the early protection/immediate motion phase (phase I), the intermediate/controlled training phase (phase II), the advanced phase (phase III), and the return to activity phase (phase IV). The timing of each phase is dependent on the fracture, the surgical procedure, and the individual progress in rehabilitation and training. The rehabilitation phases are criteria-based to ensure proper sequential progression through phase I to phase IV (Fig. 17.1).

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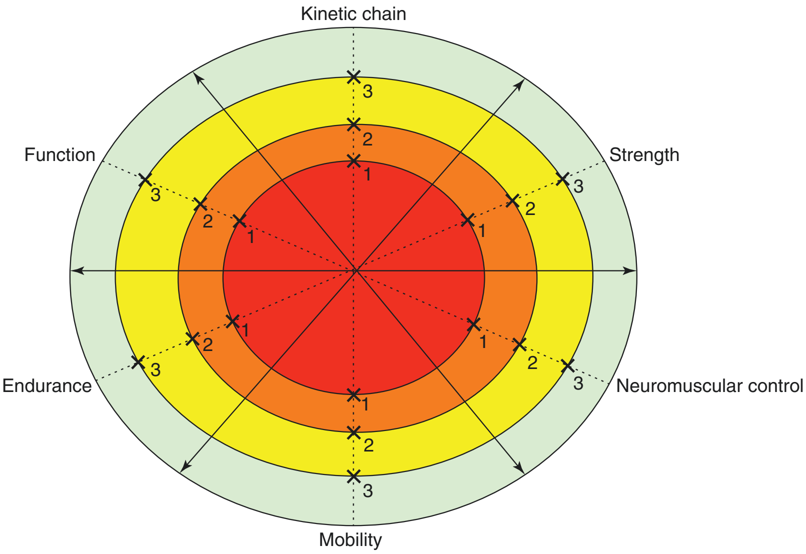

Fig. 17.1 Model of a multimodal rehabilitation approach with primary focus points. Phase I (red), phase II (orange), phase III (yellow), and phase IV (green). Intra-rehabilitative assessments (X_1–X_3)

17.2.1 Phase I (Weeks 0–3)

The goals of this phase are to ensure proper tissue healing and to reduce the effects of immobilization such as muscle hypotrophy and deficits of range of motion.

Controlled mechanical stimulation appears to be an important variable for a better repair of tissue, and early ROM exercises might be crucial to support the synthesis and the functional organization of collagen tissue (Theodoropoulos et al. 2016).

During this phase, the elbow is protected with a posterior splint for 5 days. Afterward the elbow is placed into a hinged brace with ROM limitation depending on the lesion. Especially in the early phases of rehabilitation, elbow range of motion and valgus forces are restricted to minimize stresses upon healing bony and soft tissue structures. Cryotherapy is applied for 20 min every hour for the first 3 days. A vasopneumatic compression device or a compression sleeve might be used for swelling and pain control (Reider et al. 2015). Analgesics and anti-inflammatory medicines may be necessary in the immediate postoperative phase but should be discontinued to ensure proper soft tissue healing. Therapeutic laser and electrical stimulation may be used to reduce pain and swelling.

The elbow is predisposed to flexion contractures due to the tendency of the anterior capsule to develop adhesions following surgery and injury (Wilk et al. 1993). Passive- and active-assisted ROM exercises (according to the aforementioned limitations) are started immediately after surgery to modulate pain and aid in healing tissue collagen alignment. A continuous passive motion device can be used. Manual joint mobilization techniques are performed to increase range of motion.

After suture removal, mobilization of the fascial system and the scar tissue can be performed. During this phase the patient is allowed to train on an ergometer, stationary bicycle wearing an elbow brace for cardiovascular conditioning. Scapular neuromuscular control drills, rhythmic stabilization drills, and core stability and lower extremity exercises are initiated at the end of this phase (Figs. 17.2 and 17.3). After surgery of radial head fractures, valgus strain should be avoided to protect the healing tissue. Internal rotation exercises at the shoulder can increase valgus strain on the elbow and should be avoided for 6 weeks (Bernas et al. 2009). As the elbow flexor and extensor muscles have a posteriorly directed component, concentric and eccentric muscle-strengthening exercises are restricted in early rehabilitation after coronoid fracture fixation (Morrey and An 2005).

Fig. 17.2 Squat-to-rotational press

Fig. 17.3 Rotational throw

17.2.2 Phase II (Weeks 4–7)

The criteria to progress to phase II are no effusion, pain-free elbow ROM (in the allowed ROM), healed incision without signs of infection, and effective isometric muscle control for elbow and hand extensor/flexor muscles. The emphasis of this phase is a gradual increase in elbow ROM and upper extremity muscular strength and endurance (Fig. 17.4). Neuromuscular control exercises of the elbow complex are initiated in this phase to enhance the muscular control in activities of daily living (Fig. 17.5). The hinged brace will be set at varying degrees depending on the injury that has been operated on (Table 17.1). Soft tissue mobilization is continued to decrease muscle stiffness and to prevent adhesions. Elbow isometrics (extension/flexion) are initiated at week 2 (radial head fracture) or week 4 (coronoid fracture) and gradually progressive. Neuromuscular scapular and shoulder drills are continued with increased intensity.

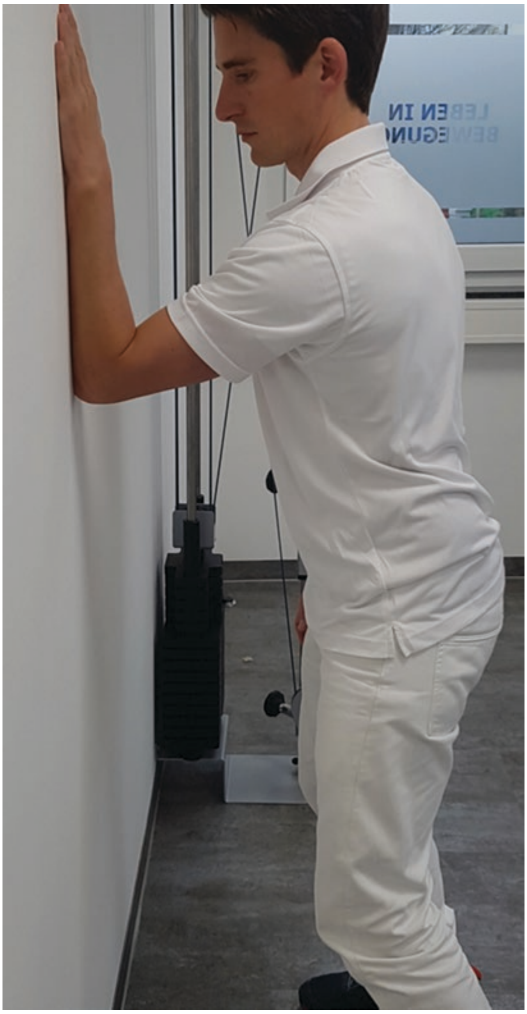

Fig. 17.4 Wall slide stretch

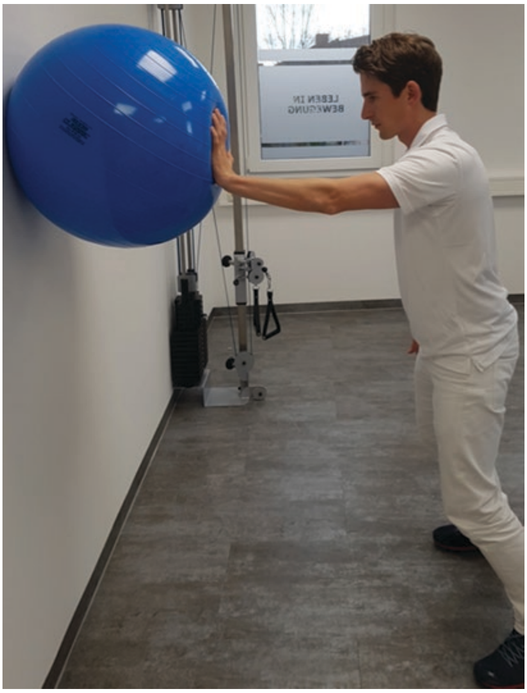

Fig. 17.5 Stabilization drills

Table 17.1 Range of motion (ROM) limitation after minimally invasive treatment of fractures involving the coronoid, the radial head, and the medial/lateral epicondyles (transcondylar)

	Coronoid	Radial head	Transcondylar
Week 1 + 2	0/0/20° (E/F)	0/20/90° (E/F) no Pro/Sup	0/20/90° (E/F) no Pro/Sup
Week 3 + 4	0/0/20° (E/F)	0/10/110° (E/F) fROM Pro/Sup	0/10/110° (E/F) fROM Pro/Sup
Week 5 + 6	0/0/60° (E/F)	fROM with hinged brace	fROM with hinged brace
Week 7 + 8	0/0/90° (E/F)	fROM	fROM

Extension (E), flexion (F), pronation (Pro), and supination (Sup). Full range of motion (fROM)

Fig. 17.6 Low-load long duration stretch

17.2.3 Phase III (Weeks 8–14)

Criteria to move to phase III are pain-free full ROM, symptom-free wrist, shoulder and scapular active movements, and a good manual muscle test (MMT) (4/5) of the elbow flexor and extensor musculature. The goals of this phase are to increase strength, power, endurance, and neuromuscular control while maintaining pain-free full ROM in order to prepare the patient to return to sporting activities. Low-load long duration stretches and manual joint mobilization techniques can be used to restore full ROM (Fig. 17.6).

Strengthening exercises are progressed during this phase, including concentric and eccentric exercises in the open and closed kinetic chain (Fig.17.7). Strength should be 70% of the contralateral extremity in isokinetic testing after 10 weeks. A complete upper extremity strengthening program, such as the Thrower's Ten program, may be performed, especially for patients involved in overhead sports (Wilk et al. 2012).

Fig. 17.7 Push-ups

17.2.4 Phase IV (Weeks 15–30)

Milestones for progression to phase IV are pain-free full ROM, adequate strength with manual muscle testing (MMT 5/5), and adequate neuromuscular control. Tests such as the Upper Quarter Y Balance Test (YBT-UQ) may be helpful to detect deficits. For the throwing athlete, emphasis is put on endurance, stability, and improving strength and agility control. Treatment for the entire kinetic chain and sport-specific drills are continued with gradual progression in this phase.

17.3 Conclusion

The integration of evidence-driven rehabilitation concepts to restore range of motion, muscle strength, and neuromuscular control forms the basis of clinical rehabilitation after minimally invasive fixation of elbow fractures.

Rehabilitation should follow a gradual and sequential progression based on constant communication between the surgeon, physiotherapist, and patient. The rehabilitation process must include the entire kinetic chain to ensure the return to sports participation. A main challenge is to integrate sports-specific elements within the rehabilitation, considering that different sports have different neuromuscular and physiological demands.

The patient is instructed to maintain forearm contact to the wall while sliding the elbow toward the floor. It is also possible to perform contract-relax techniques of the triceps or overpressure by leaning forward.

Ball on the wall stabilization exercise. The clinician may additionally provide perturbations.

The clinician can augment the range of motion stretching with low-load long duration stretch into elbow extension.

Closed-kinetic chain exercise, e.g., push-ups, performed on a BOSU ball are added for trunk and scapula stabilization.

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Part III

Arthroscopic Management of Wrist Fractures

Distal Radius Fractures

18

Halil Ibrahim Bekler

18.1 Introduction

Distal radius fractures constitute a significant part of daily orthopedic practice. One in six fractures presenting at an emergency department represents a distal radius fracture (Court-Brown and Caesar 2006). While many of these fractures can be treated safely and effectively with nonsurgical methods, intra-articular distal radius fractures can be a major problem for both the patient and the surgeon.

Distal radius fractures often occur from high-energy impact and are accompanied by intra-articular soft tissue injuries. These fractures are not stable due to their nature, and it is often not possible to treat them with closed manipulation or casting. Lafontaine et al. (1989) described the instability criteria of distal radius fractures. Patients who present with more than 20 degrees of dorsal angulation in the first radiograph, extreme dorsal bone cortex fragmentation, an accompanying ulnar styloid fracture, and intra-articular involvement and who are over 60 years of age are more prone to have an unstable fracture. These factors alone, however, are not sufficient to predict distal radius fracture prognosis. Articular cartilage injuries especially in intra-articular fractures, presence of accompanying ligament injuries, and fracture displacement more than 1 mm are among factors leading to a poor prognosis and are more likely to develop osteoarthrosis (Fernandez and Geissler 1991). The three main causes of osteoarthrosis associated with distal radius fracture include dislocation of intra-articular fractures, articular cartilage pathologies, and concomitant ligament injuries. All these factors can be treated effectively using arthroscopic methods (Edwards et al. 2001).

18.2 Intra-articular Distal Radius Fracture

The AO Foundation and Orthopedic Trauma Association (OTA) categorize intra-articular distal radius fractures as type 23 C1, C2, and C3. The most important features of these fractures include articular cartilage damage and the disruption of capsuloligamentous integrity. To prevent dorsal intercalated segmental instability (DISI) and volar intercalated segmental instability (VISI), successful distal radius fracture treatment requires good joint axis and bone length restoration and articular surface reconstruction. Intra-articular fragments are often difficult to detect. Since osteochondral intra-articular fragments are often difficult to detect, they may appear to be smaller on radiographs and on tomographic scans than they actually are. Magnetic resonance imaging is of limited help in acute cases because of

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intraosseous edema and artifacts associated with fracture site bleeding.

Since plate and screws and similar osteosynthesis materials used in distal radius fracture surgery are placed close to the joint surface, they pose a risk of joint penetration. Intra-articular ligament injuries such as scapholunate ligament injury frequently accompany distal radius fractures. If partial injuries are included, there is a 69% incidence of scapholunate ligament injuries in case of a distal radius fracture (Mehta et al. 2000). The pain associated with a distal radius fracture can make physical examination difficult, and a displaced fracture may interfere with radiographic intercarpal angle measurements.

18.3 Role of Wrist Arthroscopy for Treating Intra-articular Distal Radius Fractures

Effective distal radius fracture treatment outcomes are associated with extra-articular alignment, anatomical intra-articular fracture fragment reduction, and effective intra-articular soft tissue injury treatment. In a classic study, Knirk and Jupiter (1986) reported that even small amounts of intra-articular fragment displacement could negatively affect patient outcomes. Fernandez and Geissler (1991) quantified effective displacement reduction as being at or less than 1 mm. Wrist arthroscopy has been revolutionary in the diagnosis and treatment of these fracture fragments. Pinning of fragments under fluoroscopic control can provide good reduction in 33% of intra-articular fracture (Edwards et al. 2001). Arthroscopy use can be especially beneficial in both restoring and verifying joint surface congruity (Ruch et al. 2004).

Intra-articular soft tissue injury accompanies distal radial fractures in almost 50% of cases (Spence et al. 1998). Magnetic resonance imaging affords better evaluation of the osseous injuries that accompany distal radial fractures than conventional radiographs. However, wrist arthroscopy has become the gold standard for the detection and less invasive surgical treatment of distal radial fractures (Mehta et al. 2000). Through arthroscopy the inside of the wrist joint can be visualized effectively, fracture fragments can be detected, and the anatomic joint surface can be restored under direct observation. Concurrently, intra-articular pathologies such as scapholunate ligament injury can also be detected and treated. Intra-articular distal radius fractures, without extreme metaphyseal fragmentation, are ideal for arthroscopic treatment. Radial styloid fractures, die-punch fractures, three-piece T-fractures, and four-part fractures are all appropriate for arthroscopic treatment (Fig. 18.1a–c).

18.4 Technique

Wrist arthroscopy requires a combination of arthroscopic and hand surgery knowledge and experience in regard to injury recognition, treatment techniques, and follow-up. This is particularly true for intercarpal ligament injuries. Instruments used in larger joints cannot be used for wrist arthroscopy. It is obligatory to use instruments designed for small joints. Wrist arthroscopy is often performed using arthroscopes that are 2.7 mm or smaller. The shavers that are used to debride fracture residue and hematomas should be 3.5 mm or smaller. Considering that the intra-articular volume is very small, it is necessary to use distraction to open a sufficiently wide gap to permit surgical imaging and instrument manipulation. Vertically or horizontally positioned traction towers help facilitate arthroscopic examination, fluoroscopic imaging, and, when needed, plate and screw osteosynthesis (Fig. 18.2).

Intra-articular fractures can lead to bleeding, so it is essential that the joint be washed continuously. The 6-U portal provides the inflow, while outflow is through the arthroscopy cannula. Additional outflow can be used to prevent excessive fluid leakage into the surrounding tissues (Fig. 18.3).

Creation of a proper portal is one of the most important factors when using an arthroscope to treat an intra-articular distal radius fracture. Since the joint is of limited size, wrist arthroscopy portal creation is performed according to wrist

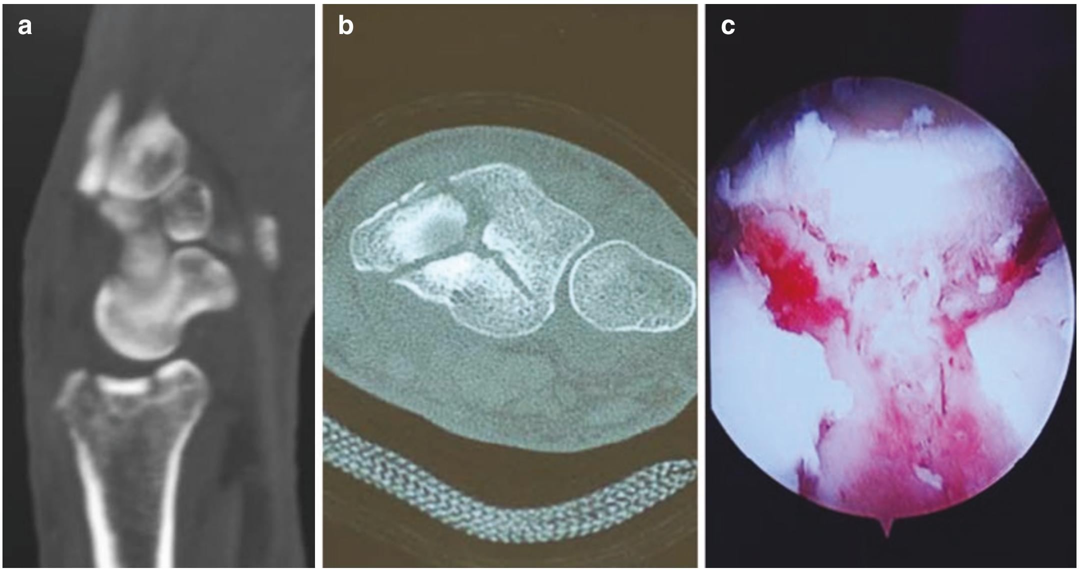

Fig. 18.1 (**a**) Die-punch fracture; a centrally located fracture is difficult to diagnose. Repositioning and subsequent fixation of this small intra-articular fragment necessitated arthroscopic observation. (**b**) CT image of an intra-articular three-part fracture. (**c**) Arthroscopic appearance of the same fracture

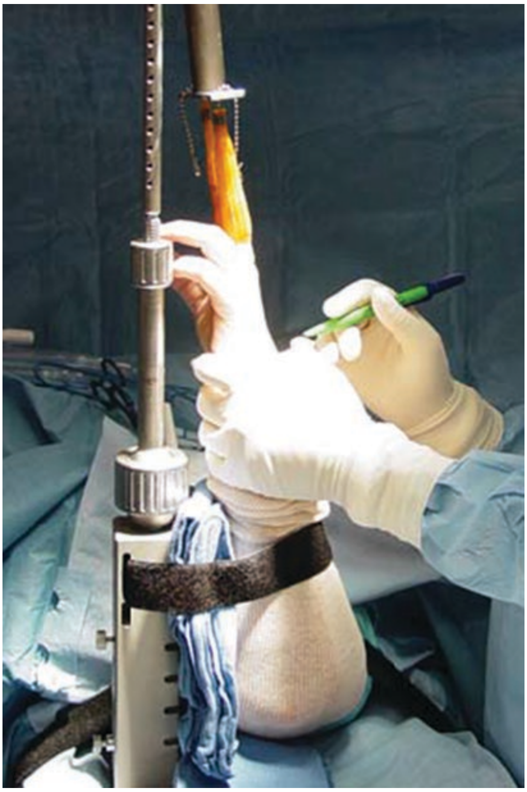

Fig. 18.2 Traction towers positioned vertically

Fig. 18.3 The 6-U portal provides inflow

extensor tendon locations, and the portals are named based on the names of these tendons. Portals 3–4 mean that the joint access is achieved by entry between the third and fourth extensor tendon compartments. However, the presence of edema makes tendon palpation difficult. Because of this, Fernandez and Geissler (1991) reported that bone landmarks should be used instead. The metacarpals, radial distal border, and ulnar head are useful bone landmarks for wrist arthroscopy. The position of portals 3–4, the most commonly used arthroscopic portal, corresponds to the radial border of the third finger.

Proper portal placement is extremely important. Even if the portal is in proper proximal-distal alignment, it may coincide with the fracture line if it is placed too proximally. Improper portal placement may make it difficult or even impossible to effectively distinguish between a fracture hematoma and intra-articular hemarthrosis. If the portal is placed too far distally, it may result in carpal injury. It may therefore be beneficial to use fluoroscopic guidance to assist with portal placement. During portal placement, the surgeon inserts an 18-gauge needle tip and palpates with the thumb. If the needle tip feels as though it is inside the joint, an incision is made.

The ideal timing for arthroscopic distal radius fracture treatment is 3–10 days after injury. Any intervention performed during the early, acute period will lead to bleeding and make arthroscopic visualization difficult. Interventions performed after the 10th day are associated with difficulty in bone disimpaction and reposition of the fracture fragments.

18.5 Radial Styloid Process Fractures

Radial styloid process fractures comprise the least technically complicated fractures for arthroscopic fracture reduction and fixation. After traction application, the arthroscope is inserted via portals 3–4 to enable fracture fragment reduction under direct visualization. However, portals 4–5 or 6-R may better enable direct observation if the fragment is radially rotated. In case of displacement, a K-wire applied to the distal radial fragment may be used as a "joystick" to correct the rotational deformity. The scope is at 6-R at this time, and a trocar inserted through portals 3–4 aids in the reduction (Fig. 18.4a, b).

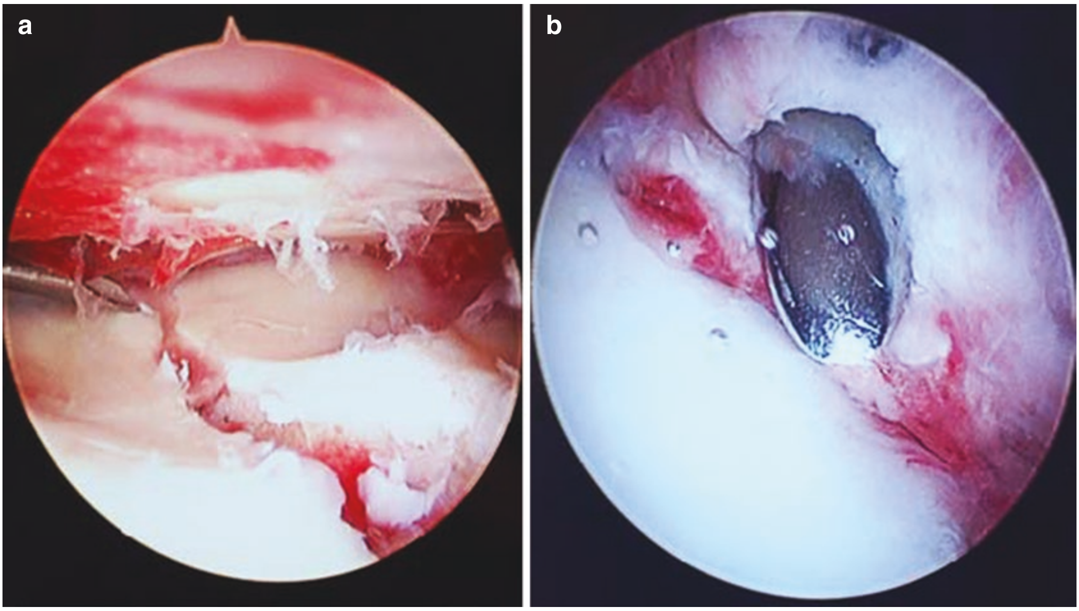

Fig. 18.4 (**a**) Displaced intra-articular distal radius fracture. (**b**) Reposition maneuver of the fracture

If reduction is successful, fixation can be performed using either a cannulated screw or K-wires. During this procedure, it is important to avoid injury to the dorsal sensory branch of the radial nerve during screw or K-wire insertion into the radial styloid. Working through a mini-incision over the radial styloid may help locate and better protect this nerve. A cannula can also be used for this purpose. Scapholunate ligament injuries frequently occur with radial styloid fractures. After radial styloid process fixation is achieved, the arthroscope is once again inserted into portals 3–4 again to assess scapholunate ligament integrity. If necessary, a midcarpal arthroscopy can be performed to better verify the integrity of this ligament.

18.6 Three-Part Fractures

Three-part fractures represent radial styloid process and lunate facet fractures. For these fracture types, the radial styloid process fragment serves as a landmark for the more difficult process of lunate facet reduction. The radial styloid process fragment is reduced under fluoroscopic guidance as a starting point. Once reduction and stabilization are achieved, the wrist is suspended from the traction tower. The fracture residue and hematoma are then debrided. The lunate facet is best observed through portals 3–4. An 18-gauge needle should immediately be applied to the depressed fracture fragment to enable fixation. A Steinmann nail is applied 2 cm proximal to the needle. The nail acts as a lever to elevate the depressed fracture fragment. This maneuver may also be performed using an elevator. Once the lunate facet is restored to its desired level, guidewires are advanced through the subchondral radial styloid process to the lunate facet. If the die-punch fragment is located dorsally, the guidewire should be directed dorsally. Since the die-punch fracture fragment is fixed with transversely positioned K-wires or cannulated screws, there is a risk of distal radioulnar joint penetration. Before final fixation, the restoration of wrist joint range of motion should be verified using a pronation-supination maneuver. To eliminate the possibility of irritation from subcutaneous K-wire tips, headless cannulated screws may be used. This will also facilitate early rehabilitation.

If the metaphyseal fracture comminution is advanced, a volar plate should be applied using a standard volar approach. The wrist is positioned using a traction tower following fracture reduction and fixation to enable arthroscopic verification of intra-articular fracture reduction and fixation integrity. If fracture reduction and articular surface congruity are not deemed adequate, the screws are removed from the plate, and the fragments are liberated. Careful manipulation is then performed to reposition fracture fragments under arthroscopic control. With proper reduction, the screws are reapplied. This control is especially important for the surgical management of die-punch fractures. Dorsal die-punch fragments are best observed through portal 6-R or through the volar portal (Slutsky 2004; Slutsky 2007). This portal is created from the volar side, between the radioscaphocapitate ligament and the long radiolunate ligament.

18.7 Four-Part Fractures

In four-part fractures, there are volar and dorsal fragments that form the lunate part (die-punch). The volar fragment cannot be reduced using closed maneuvers. Just like in three-part fractures, the first stage involves closed reduction and fixation of the radial styloid process. Using a standard volar approach, the radial styloid process fragment is reduced under direct visualization and fixed temporarily using K-wires. The volar ulnar fragment is also identified through a volar approach. The volar ulnar fragment is also fixed temporarily to the radial shaft and the radial styloid process using K-wires. A volar plate is then applied to the distal radius. With the wrist suspended from a traction tower, the arthroscope is inserted in portals 3–4. The dorsal ulnar fragment is best visualized through portal 6-R and the Slutsky portal. The dorsal ulnar fragment is elevated percutaneously and is then fixed to the ulnar volar fragment using two K-wires. Final fixation is achieved using the volar plate and screws, which are inserted under direct arthroscopic visualization.

Postoperatively, a protective volar orthosis was applied to all distal radius fractures. At the first visit, 2 days postoperatively, plain posteroanterior, lateral, and oblique radiographs were obtained. A volar resting orthosis is worn for patient comfort until sutures were removed. Self-directed active and assisted exercises were encouraged at that time. After 4 or 5 weeks, full motion was allowed. The arthroscopic treatment of the intra-articular distal radius fractures is a relatively new method and has a short follow-up period; no definitive conclusions can be made regarding the long-term efficacy of this procedure. However, this procedure has the undeniable advantage of minimal morbidity, keeping multiple future treatment options.

18.8 Conclusion

Arthroscopic reduction of a distal intra-articular radius fractures provides a benefit over fluoroscopy in determining joint surface congruity. Wrist arthroscopy is a feasible adjunct for the treatment of distal radius fracture management. Wrist arthroscopy is especially effective to evaluate osteochondral surfaces and soft tissue injuries and verify intra-articular fragment reduction and fixation.

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19

Distal Radius Fractures with Metaphyseal Involvement: "Minimally Invasive Volar Plate Osteosynthesis"

Miguel A. Capomassi and Miguel H. Slullitel

19.1 Introduction

Distal radius fractures account for approximately 16% of all skeletal fractures; the most commonly affected group are women over 60 years old (Chung and Spilson 2001). These fractures usually result from low-energy trauma, often in patients with osteoporosis (Singer et al. 1998). Nevertheless, distal radius fractures have a characteristic bimodal distribution, also present in patients with normal bone metabolism who have suffered high-energy trauma caused by road or work accidents. In this second group, the fracture patterns can be more complex, involving the radius metaphysis and even extending to the diaphysis.

At the moment, despite controversy in terms of treatment, the use of volar locking plates appears to be the most widely preferred surgical choice for these fractures (Chung and Petruska 2007). Placed through the Henry volar approach, these plates provide stable fixation, allowing the use of controlled early mobilisation and prevention in almost all patients and the use of grafts or bone substitutes (Imantani et al. 2005; Guiterrez Olivera et al. 2015). Yet, the internal fixation by means of volar plates in fractures involving the metaphysis may require extended approaches, involving the disinsertion of the pronator quadratus, which acts as a dynamic stabiliser of the distal radio-ulnar joint (DRUJ) and as an integral component of the joint proprioceptive system (Guiterrez Olivera et al. 2015; Hagert 2010; Hagert et al. 2016; Sen et al. 2008). Moreover, the direct handling of bone fragments has a negative effect on their vascularisation, thus contributing to the development of complications such as infection, bone necrosis and delayed fracture consolidation.

Modern minimally invasive plate osteosynthesis (MIPO) techniques were first developed and used to stabilise articular or para-articular fractures of the lower limbs. The aim of these techniques was to restore the anatomical axes through indirect reduction manoeuvres and to achieve a mechanically stable osteosynthesis assembly using locking plates while simultaneously preserving the integrity and vascularisation of the surrounding soft tissues and fracture hematoma, which are essential to callus formation (Gustilo and Anderson 1976; Keast-Butler and Schemitsch 2008).

This "biological osteosynthesis" was later applied to the traumatic pathology of the upper limb. The method has been in use for several years for the treatment of humerus fractures; however, its application has not been widespread in terms of radius fractures (Ganz et al. 1991; Hanel et al. 2006; Keast-Butler and Schemitsch 2008; Krettek et al. 1997; Ruch et al. 2005).

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This chapter addresses the use of the MIPO (the minimally invasive plate osteosynthesis) technique in distal radius fractures that extend to the metaphyseal area and frequently present with comminution but with mild involvement or no involvement of the distal epiphysis.

The anatomical and biomechanical aspects of the surgical technique, its description and plausible complications and final conclusions are included in this chapter.

19.2 Anatomical and Biomechanical Concepts

Undoubtedly, the functional result obtained after the surgical treatment of a distal radius fracture depends not only on adequate alignment of joint fragments, and on the restoration of the relative length, but also on the achievement of a high degree of preservation of the surrounding soft tissues. This is secured through a rigorous surgical technique (Drobetz et al. 2006; Orbay and Touhami 2006).

The pronator quadratus, which is frequently injured either by trauma or by surgical manipulation in a fracture affecting the metaphyseal area of the radius, plays a very important anatomical and biomechanical role. With a 5-cm-long and 4.2-cm-wide fleshy belly, this muscle runs from the ulna to the radius in a “scarf-like” fashion. Distally, it also has an 8–10-mm-long retinacular portion, which merges with the joint capsule and palmar ligaments (Lamas et al. 2009; Rath et al. 1990). The two muscle components are separated by the so-called watershed line, an anatomical landmark crucial to appropriate osteosynthesis plate placement technique. By means of its fleshy belly, the pronator quadratus provides an anatomical plane of isolation, keeping the implant separated from the flexor tendons, which are perpetually vulnerable to friction against the distal edge of the plate. The integrity of this muscle or its repair after it has been cut during surgery is a matter of paramount importance.

Also, the pronator quadratus, supplied by the anterior interosseous artery (AIA), which runs deep below the muscle belly and against the interosseous membrane, has a fundamental role, as is clearly shown by numerous anatomical reports related to the vascularisation of the distal radius and consequently the process of bone regeneration (Lamas et al. 2009; Rath et al. 1990). With reference to the biomechanical aspects, it should be noted that the stability of a joint depends on the congruence and geometry of its surfaces, on the integrity of its capsule and ligaments (static stability) and on muscle action (dynamic stability), i.e. achievement of coaptation by means of muscle contraction (Hagert et al. 2016). Indeed, both the capsule and ligaments possess mechanoreceptors that when activated send information to the brain through afferent pathways, thus enabling neuromuscular and proprioceptive control (Hagert 2010).

In addition, the pronator quadratus, which receives its innervation from the anterior interosseous nerve (AIN), is an essential link to the sensorimotor system. This system represents the interaction between static and dynamic stabilisers and is meant to secure an adequate joint function and stability.

It is clear, then, that the surgical treatment of distal radius fractures with metaphyseal involvement aims not only at achieving good reduction but also at respecting the integrity of the capsule-ligamentous and neuromuscular systems. In this respect, the ultimate goal of the minimally invasive plate osteosynthesis technique is to restore joint morphology through indirect reduction while maximising the preservation of structures that are vital.

19.3 Surgical Technique

The surgical procedure can be carried out as day patient care only, provided this is not contraindicated due to old age, health status, prior illnesses or polytrauma.

The patient is positioned in supine with the affected limb resting on a radiolucent operating table. *Step I*: Using image intensifier control, longitudinal traction is applied to achieve an indirect reduction and to restore the radial axes and the relative radio-ulnar length. If this goal is attained, a 1.5–1.8-mm Kirschner (K) wire can be inserted at the level of the radial styloid apophysis to provide temporary fixation. If necessary, a second wire can be directed either towards the dorsal or the palmar side. The distal skin incision, a 2–3-cm transverse or oblique incision (the latter following a plane parallel to the joint surface), is then made proximally to the wrist flexion crease. Next, the superficial flaps are elevated, and the approach deepened between the flexor carpi radialis tendon and the radial vascular bundle while gently retracting the flexor pollicis longus ulnarly. As a result, the pronator quadratus is exposed. At this point, an incision is made through the retinacular portion of the muscle. Avoidance of any violation of the capsule and of the palmar radiocarpal ligaments during this manoeuvre is crucial (Fig. 19.1). Once the incision has been made, the pronator quadratus is raised from its distal edge towards its proximal one with a blunt dissector, thus creating a tunnel underneath the muscle belly. Then, the longitudinal branch of the plate is slid through the tunnel (Fig. 19.2) (Guiterrez Olivera et al. 2015).

Step II: The plate is aligned over the radial shaft, establishing the correct length of the implant. Long locking plates, with 6–7 drill holes, are usually necessary to bridge the metaphyseal area. After the plate has been aligned, the proximal skin incision, a 2–3-cm longitudinal incision centred over the diaphyseal axis of the radius, is made (Fig. 19.3). The first screw is then placed in the oblong hole so as to facilitate any implant position adjustment that may be required. It is essential to bear in mind that the plate must not extend beyond the watershed line to avoid a friction injury to the flexor tendons. Longitudinal traction is maintained, and once the radial length and axes have been restored, locking screws or pegs are fixed in place. These must run through the subchondral bone and provide adequate mechanical support to the palmar, central and dorsal portions of the epiphysis. If the reduction at the metaphyseal level becomes too complex, the manoeuvre can be assisted by a dissector placed through the distal incision. At the end of this step, the proximal screws are secured, trying to ensure they are in the centre of the radial shaft in order to achieve bicortical fixation, most important in osteoporotic bones (Fig. 19.4).

Step III: The radiographic images must show satisfactory restoration of the radial axes and length and of the radio-ulnar joint congruence (Fig. 19.5). Images must also confirm the

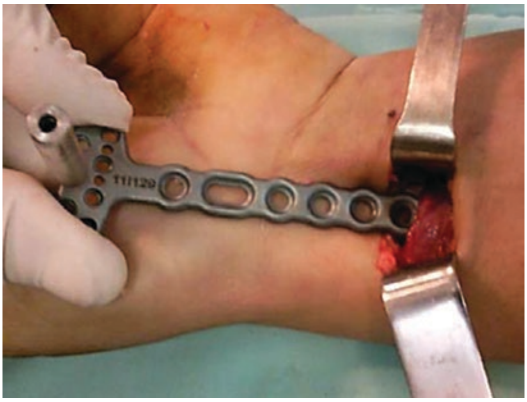

Fig. 19.2 The plate is slid under the pronator quadratus

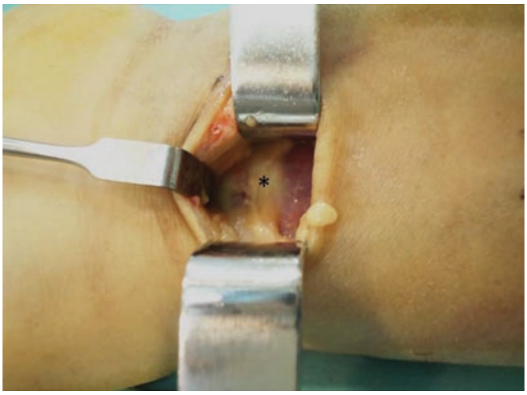

Fig. 19.1 Distal incision. The asterisk [*] indicates the retinacular portion of the pronator quadratus

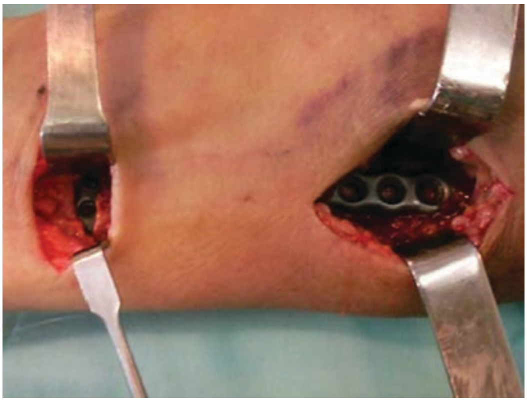

Fig. 19.3 The plate is placed in the correct distal position. Proximally, it has been brought into alignment with the radial shaft

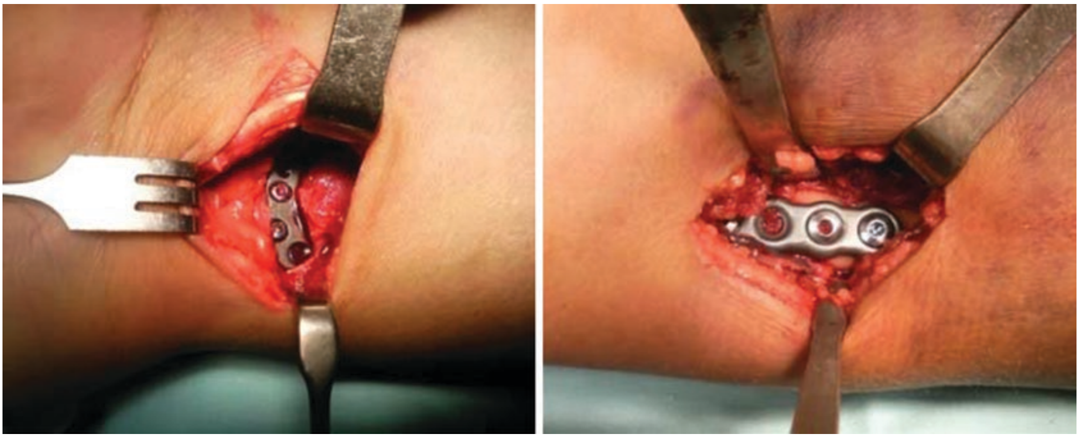

Fig. 19.4 Final osteosynthesis

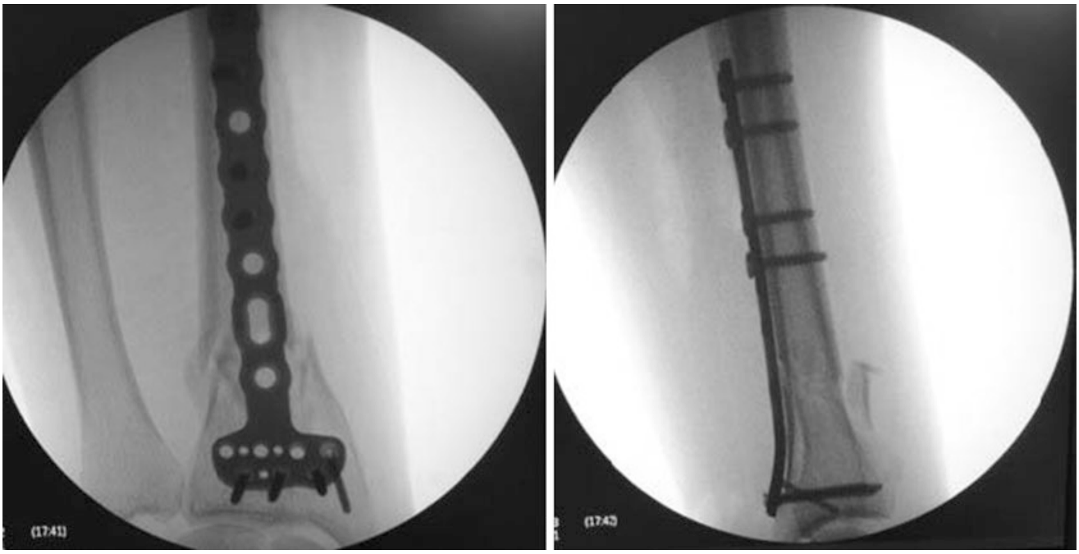

Fig. 19.5 Radiographic assessment. The radial length and alignment are correct. The plate is bridging the comminuted metaphyseal area

appropriate location of the distal screws. This is best evaluated through a lateral projection of the wrist, taken with the elbow at 30 degrees of flexion (X-ray beam tangent to the joint surface) so as to detect, or rule out, the presence of intra-articular screws. Once these parameters have been checked, closure of the retinaculum of the pronator quadratus is performed to cover the distal portion of the plate and to protect flexor tendons from friction (Fig. 19.6). The initial dressing of the surgical wound is complemented with a padded bandage and a dorsal plaster splint.

Fig. 19.6 Sutured surgical wounds

19.4 Rehabilitation Protocols

After surgery, the patient is instructed to keep their operated hand elevated during the early post-operative period. Also, active motion of the fingers, flexion and extension of the elbow and anterior elevation of the shoulder are encouraged. Only prono-supination of the forearm is partially restricted, particularly when required by the complexity of the fracture or if a concomitant reconstructive procedure has been carried out.

As of the second post-operative week, if the fracture pattern allows it, splint use is discontinued in order to start the initial stage of the rehabilitation process, which aims at reducing soft tissue swelling and stimulate passive and active assisted movements (Lozano-Calderson et al. 2008; Brehmer and Husband 2014). One month after surgery, the first radiographic assessment is carried out (Fig. 19.7). If the osteosynthesis assembly remains stable and an incipient callus formation is present, active motion is intensified (maintaining a restriction on rotation movements), and proprioceptive training is initiated.

Six weeks after surgery, the use of all external protective devices is definitively ceased, and the patient starts light activities of daily living (ADLs). At this point, progressive muscle strengthening exercises are also started.

By the eighth post-operative week, and provided a consistent evolution of the fracture callus is confirmed through a new radiographic assessment, restrictions on the movement of the affected limb are progressively removed while continuing with the proprioceptive training and progressive muscle strengthening exercises. Three months after surgery, the patient is back to full activity and returns to their routine tasks, except for those requiring maximum loads or for contact sports. At 6 and 12 months post-surgery, new radiographs are taken (Figs. 19.8 and 19.9) (Hudak et al. 1996). If comminution in the metaphyseal fracture is extensive, demanding the use of very long plates to bridge the defect,

Fig. 19.7 One-month post-operative radiographic assessment. The initial bone callus can be seen

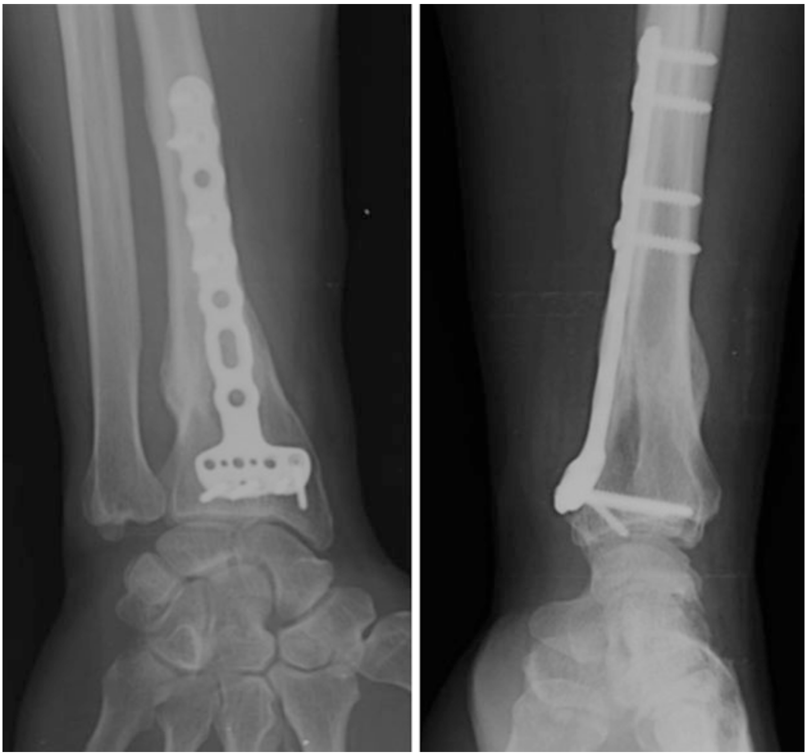

Fig. 19.8 Six-month post-operative radiographic assessment. Definitive bone consolidation

Fig. 19.9 Six months after surgery. Mobility

the controlled early mobilisation standard protocol may be subjected to modifications, especially in the presence of osteoporotic bone. In this particular situation, it is useful to protect the patient using a plaster cast for a period of 25–30 days; this cast is then replaced by a splint that leaves the elbow free and is worn until the sixth or eighth post-operative week. The goal of this additional external immobilisation is to reduce the stress exerted on the plate by axial and rotatory loads, thus decreasing the likelihood of implant failure.

The controlled early mobilisation standard protocol renders better mobility and strength and higher disabilities of the arm, shoulder and hand (DASH) scores in the first post-operative months, compared with longer immobilisation. Nevertheless, the decision to choose between one mobilisation therapy and the other is mainly based on the stability of the MIPO technique.

19.5 Discussion

The use of MIPO for bone fixation was first introduced as a treatment for proximal and distal femoral fractures with metaphyseal extension (Krettek et al. 1997). The use of conventional plates applied through a submuscular tunnel has been proven to produce a positive outcome, resulting from preserving both the fracture hematoma and the bone vascular supply (Krettek et al. 1997).

The development of locking compression plates (LCP) has contributed greatly to a more "biological" fixation of fractures. The MIPO technique is much newer method than the LCP. Even though the minimally invasive osteosynthesis technique was first employed in the treatment of complex lower limb fractures involving osteoporotic bone and associated to soft tissue injuries, over the past years, the use of this technique has expanded to also be applied in the management of upper limb trauma. After its first use in humerus fractures, a small number of reports have commented on its value in the treatment of distal radius fractures (Orbay and Fernandez 2004).

In the last years, the good results obtained with volar locking plates have granted them widespread approval. Yet, the placement of these plates in fractures involving the metaphyso-diaphyseal area of the radius by means of a conventional open surgery has a negative impact on vascularisation and predisposes to scar formation and joint stiffness. In fact, it is the implantation of the plate through mini-incisions and the act of sliding it underneath the pronator quadratus that actually reduce vascular damage and enhance bone consolidation, thus promoting satisfactory results. In a case series of five patients who had distal radius fractures with metaphyseal involvement who were operated on using volar locking plate (T plate) inserted using a minimally invasive technique, and without pronator quadratus cutting, Imatani et al. (2005) reported 100% consolidation, with good anatomical and functional results in all patients. Benefits from MIPO application include soft tissue preservation and a low risk of complications, including hematomas, adhesions and flexor tendon injuries (Sen et al. 2008). Nevertheless, the main technical problem associated with this procedure is the difficulty to achieve adequate fracture reduction through the small incisions. When this occurs, it is suggested to resort to the conventional approach. The study of Sen et al. (2008) clearly showed that fractures that extend to the metaphyso-diaphyseal area, and have mild joint involvement, benefit the most from the minimally invasive technique.

A case series of 66 patients with distal radius fractures treated with volar plates either implanted conventionally ($n = 36$) or using a minimally invasive technique ($n = 30$) was reported (Zenke et al. 2011). The authors showed that the DASH and visual analogue scale (VAS) scores were lower and patient satisfaction was higher using the minimally invasive technique group. The report however did not specify whether fractures with metaphyseal extension were included or not (Zenke et al. 2011).

A case series of 21 patients with diaphyseal involvement of the radius fracture treated with fixed-angle locking volar plates using the conventional Henry approach evaluated fracture consolidation (Rampoldi et al. 2011). With the exception of one patient who required a secondary bone graft, the average consolidation time for all patients was 90 days. In 19 patients, the Mayo Wrist Score ranged from good to excellent (Rampoldi et al. 2011). A case series of 22 consecutive patients with distal radius fractures and metaphyso-diaphyseal extension that had been stabilised with an extra-large (2.4-mm) volar locking compression plate (LCP) placed through a conventional approach showed an average consolidation time of 16 weeks (Lee et al. 2013). According to the Gartland and Werley Score, outcomes were excellent in 14 patients and good in 5 (Lee et al. 2013). Both of these studies (Lee et al. 2013; Rampoldi et al. 2011) concluded that, in these complex fractures, osteosynthesis by means of locking plates that were placed through a conventional volar approach was an efficient treatment with a low complication rate.

A case series of 20 distal radius fractures stabilised with plates inserted through a minimally invasive approach evaluated the difficulty in achieving indirect reduction in some of these complex fractures (Zemirline et al. 2014). This study included a variety of distal radius fractures and was not exclusively limited to those with a metaphyseal extension (Zemirline et al. 2014).

Others have reported clinical results using long volar plates with the minimally invasive technique (21 patients) compared with the conventional approach (13 patients) for treating metaphyso-diaphyseal radius fractures (Chen et al. 2015). Some researchers have concluded that the MIPO technique produced as good results as conventional one, brought greater satisfaction to the patients and required smaller incisions and shorter surgery times. Nevertheless, they advised against using this approach in complex fractures that demand anatomical reduction of the joint surface (Chen et al. 2015). The procedure permits satisfactory reduction and achievement of stable fracture fixation with minimal post-operative pain and good cosmetic and functional results. Although some percutaneous methods, such as the trans-articular external fixation, have been used in the treatment of unstable fractures with metaphyseal comminution, in recent years, the non-satisfactory results and the high incidence of complications, i.e., infections and complex regional pain syndrome (CRPS), have restricted the indication of these methods to fractures presenting with severe soft tissue injury as a result of high-energy trauma (Hayes et al. 2008; Wolfe et al. 1998).

Fixation performed through minimally invasive approaches is indicated in distal radius fractures with metaphyseal involvement that do not require direct articular fragment reduction. In this context, the use of volar locking compression plates minimises soft tissue, and bone vascular system injury facilitates the consolidation process and reduces the incidence of complications. Yet, the procedure is technically demanding. Restoration of the length and of the anatomical position of the distal radius is essential to attain satisfactory functional results.

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20

Arthroscopic Treatment of Scaphoid Fractures

T. L. Whipple

20.1 Diagnosis and Mechanism of Injury

Scaphoid fractures are the most common carpal bone fractures to occur in the wrist. Early diagnosis is key to adequate fracture treatment, and diagnosis is often delayed due to the apparently normal appearance of a broken scaphoid on early radiographs after injury. Localized tenderness to palpation in the anatomic snuffbox following wrist trauma should raise a high index of suspicion of a carpal scaphoid fracture. Early immobilization of the wrist and thumb in a thumb spic cast or splint is the most prudent treatment option when a carpal scaphoid fracture is suspected. Early resorption of bone adjacent to the fracture due to the initial inflammatory reaction often increases the apparent breadth of the fracture line, making it more readily apparent on delayed radiographs a week or two after the trauma. Although a fall onto the outstretched hand is the most common mechanism of injury for scaphoid fractures, that is by no means the only mechanism for a scaphoid fracture injury.

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20.2 Anatomy

The carpal scaphoid is a peanut-shaped bone on the radial aspect of the proximal carpal row. The name derives from the Greek word “skaphe”, which means “boat,” although it more closely resembles a peanut than a boat. The scaphoid articulates with the distal radius proximally, the lunate and the capitate to its ulnar side, and the trapezium and trapezoid carpal bones distally. These articulations are stabilized by strong ligaments that attach distally and proximally. Thus, the scaphoid provides a long mechanical lever connecting the proximal carpal row with the distal carpal row. Most of the proximal and distal poles of the scaphoid are covered with articular cartilage. The midsection or waist of the scaphoid is devoid of articular cartilage. It accommodates firm attachment to the radiocarpal joint capsule. On its volar aspect, this is predominantly represented by the oblique radioscaphocapitate ligament which provides a fulcrum about which the scaphoid pivots during wrist flexion and extension. It is this strong, volar ligament that produces the so-called humpback deformity of scaphoid waist fractures due to flexion-deforming forces.

Blood circulation supplied to the carpal scaphoid is unique. It enters the bone at the dorsal distal pole from a branch of the radial artery and then flows through the scaphoid from distal to proximal, supplying 70–80% of the bone,

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including the proximal pole. Secondary vessels from the palmar arch enter the distal pole of the scaphoid on its volar side, supplying the scaphoid tubercle. Thus, fractures of the waist of the scaphoid and transverse fractures through the proximal pole of the scaphoid jeopardize blood circulation to the proximal pole, increasing the incidence of avascular necrosis of the proximal pole.

20.3 Fracture Types

Fractures through the waist of the scaphoid are the most common fracture patterns of this carpal bone, due to the flexion force over the strong radioscaphocapitate ligament, as described. In a fall onto the outstretched hand striking the palm, the wrist may be relatively extended and the load is transferred through the trapezium and trapezoid onto the dorsal aspect of the distal pole of the scaphoid. The scaphoid, in turn, flexes about the radioscaphocapitate ligament producing a flexion-deforming force and a "humpback deformity" or dorsally angulated fracture of the scaphoid waist.

Transverse fractures of the proximal pole of the scaphoid typically occur with the wrist at greater angles of extension. The trapezium and trapezoid articulate with the scaphoid farther dorsally on the distal pole in wrist extension, shifting the fulcrum of the radioscaphocapitate ligament farther proximal on the scaphoid causing the transverse fracture. Here, the blood supply to the proximal pole is more tenuous and more susceptible to complete disruption.

The third most common fracture type of the scaphoid is a chip fracture, usually at the volar radial site of the extrinsic scaphotrapezium capsular ligament attachment. Such chip fractures may occur with hyperextension of the wrist, extension combined with ulnar deviation of the wrist, or with a direct blow to the volar radial aspect of the wrist. Usually, the chip fragment represents an avulsion of the scaphotrapezium ligament.

Long, spiral oblique fractures of the scaphoid are least common, but certainly worth noting. As the scaphoid pivots over the radioscaphocapitate ligament, the scaphoid pronates as it flexes. This accounts for the ability of the wrist to deviate farther ulnarward in flexion than it can deviate radialward in flexion. In ulnar deviation of the wrist, the radioscaphocapitate ligament courses more obliquely across the volar surface of the scaphoid than in radial deviation of the wrist. The long, radial oblique fractures through the waist of the scaphoid, therefore, are more likely to be seen from falls backward or to the side onto the outstretched hand when the wrist is held in ulnar deviation to break the fall. These long, oblique fractures invariably course from the distal ulnar aspect of the scaphoid to the proximal radial aspect, when viewed on an anterior-posterior radiograph. Ulnar deviation of the wrist also serves to pull the volar radioscaphocapitate ligament tighter and narrower, making it more incisive on the volar cortex of the scaphoid.

Nonunion: Nonunion of the carpal scaphoid usually is the result of disruption of the bone's internal blood supply or, in the case of avulsion chip fractures, physical separation of the bone fragments. In chip fractures, the smaller avulsed chip of bone from the scaphoid tubercle may retain adequate blood supply from its residual capsular attachment and remain viable. However, it may be separated completely from the body of the scaphoid, making it impossible for osteogenesis to bridge the separation gap.

With transverse waist fractures or proximal pole fractures, the intraosseous, retrograde blood supply is often disrupted. Without anatomic reapproximation of fracture fragments, revascularization may be insufficient to maintain viability of the proximal pole and osteonecrosis may ensue with nonunion of the fracture. Viability of the proximal pole depends on early anatomic reduction of the fracture fragments and adequate immobilization to permit vascular regeneration. These considerations are mandatory in planning surgical fixation of transverse proximal pole scaphoid fractures.

20.4 Fracture Treatment

There are several treatment options for fractures of the carpal scaphoid. For discussion, they can be subdivided into two groups, nonoperative and operative. However, selection of one category versus the other is not a simple matter. As the potential for fracture nonunion requires concern for the intraosseous circulation of the fracture fragments, nonoperative treatment may fail to adequately reduce the fracture fragments to one another to accommodate revascularization, or may not sufficiently immobilize the fragments to permit revascularization for mature fracture healing. Conversely, operative management might accomplish anatomic reduction but employ fixation hardware that would jeopardize intraosseous circulation pathways.

Nonoperative treatment of wrist trauma with localized tenderness to palpation of the anatomic snuffbox should anticipate the probability of a scaphoid fracture. If the scaphoid appears to be normal on radiographs, the best method of immobilization is a well-molded, short-arm thumb spica cast. Wrist gauntlet casts and removable thumb spica splints are inadequate to maintain immobilization of a suspected scaphoid fracture for the first several days until delayed radiographs at two or three weeks after the injury confirm the presence or absence of a fracture.

A fracture that is radiographically evident must take into account the fracture type, its potential injury to intraosseous circulation, the presence of deformity within the anatomic puzzle of the carpus, the potential for fracture fragment remodeling and, equally important, the patient's ability and compliance with limitations imposed by the treatment elected. Patients who are less likely to comply with immobilization instructions better should be treated more aggressively. Patients who have lifestyles, family or employment obligations that would preclude lengthy cast immobilization or who have limited finances to permit surgical treatment are best managed with mutually agreeable techniques and full explanation of the associated treatment risks.

The advantages of surgical treatment options include adequate reduction of the fracture deformity, maintenance or stabilization of that reduction and restoration or accommodation of circulation to the fracture fragments. Rarely is there a need to consider bone grafting for an acute scaphoid fracture unless the quality of bone in the elderly or concomitant disease states mandate that concern, or if the volar cortex is so crushed, it will not support reduction of a humpback deformity.

20.5 Open Versus Arthroscopic Surgical Treatment

Arthroscopic surgery provides two major advantages over open treatment of acute scaphoid fractures. Arthroscopic scaphoid fracture treatment does not provide for speedier recovery, as minimally invasive or arthroscopic approaches might permit for other surgical wrist procedures. Arthroscopic scaphoid fracture treatment does permit a more cosmetic final result when surgical treatment is advisable. Arthroscopic fracture treatment also permits better preservation of the critical extrinsic and intrinsic wrist ligaments than do conventional open surgical approaches. Ligament preservation permits greater stability of the carpus, speedier rehabilitation after fracture healing, and less potential for developing post-traumatic osteoarthritis following surgery.

Arthroscopic approaches to scaphoid fractures can be performed with traction applied through the index and long fingers or, alternatively, traction applied to the thumb or both. Visualization of the fracture for stabilization may be best attained from the radiocarpal space or the midcarpal space, but both approaches should be used for a final assessment of adequate fracture reduction before concluding the procedure.

Waist fractures: Arthroscopic reduction of waist fractures is achieved most effectively by using ligamentotaxis, accomplished with the traction applied to the fingers and/or to the thumb. External pressure or percutaneous K-wire joysticks can be used, as necessary, to complete fracture reduction under arthroscopic visualization. Maintenance of the fracture reduction can be accomplished by means of multiple K-wires or by using a headless, intraosseous compression screw.

K-wires can be introduced across the fracture site under fluoroscopic control from distal to proximal or proximal to distal. Proximal to distal pinning usually requires wrist flexion to afford access to the proximal pole of the scaphoid to pass K-wires down the axis of the scaphoid. Care should be taken not to lose fracture fragment reduction when flexing the wrist. Postoperative immobilization of the fracture in this flexed position may be necessary to prevent K-wires from marring the articular surface of the scaphoid fossa of the radius. For these reasons, it may be preferable to introduce multiple K-wires for fixation from distal to proximal without flexing the wrist, although it is more accurate to place a central axial wire from the proximal approach if one plans to use it as a guide wire for insertion of an axial cannulated screw (Merrell and Slade 2008).

Alternatively, scaphoid waist fracture reduction can be maintained by placing two K-wires through the distal pole and into the capitate and two K-wires through the proximal pole and into the capitate, thereby avoiding the articular surfaces of the scaphoid proximally and distally. This technique, however, requires anatomic fracture reduction and does not permit fracture compression.

Arthroscopic placement of an axial compression screw is an alternate consideration to K-wires. In 1984, Timothy Herbert designed a headless screw for this purpose (Herbert et al. 1992). The screw has threads with different angles of pitch at either end and a non-threaded midsection. This provided a degree of fracture compression as the screw progresses faster through the second fracture fragment, lagging it tightly to the first fracture segment. This headless compression screw is inserted from distal to proximal using an open, volar surgical approach. In humpback deformities with significant comminution of the volar cortex of the scaphoid, a cortical bone graft can be inserted on the volar side of the scaphoid to bridge the gap produced when the humpback deformity fracture is reduced.

The author designed a compression-fixation guide to permit axial placement of an intraosseous compression screw through the central axis of the scaphoid from distal to proximal, using an arthroscopically assisted minimally invasive approach (Whipple and Ellis 1991). The compression guide accommodates a preliminary axial K-wire over which a cannulated Herbert-Whipple screw can be placed while maintaining fracture compression (Whipple 1992). Whether starting distally or proximally, a cannulated intraosseous compression screw will maintain fracture reduction and permit earlier wrist mobilization than K-wire fixation.

Several models of headless compression screws have been devised. All will accomplish the objective of rigid scaphoid fixation. Two important considerations should guide the appropriate screw design selection for scaphoid fractures. First, the diameter of the axial screw may impede further the restoration of intraosseous, retrograde circulation to the proximal bone fragment. Thus, a screw of larger diameter will be disadvantageous. Second, if introduced from proximal to distal, the screw will disrupt the smooth articular surface of the proximal pole of the scaphoid which articulates with the radius, risking development of iatrogenic radio-scaphoid arthrosis (Merrell and Slade 2008). Multiple attempts at correct retrograde screw placement pose additional risk to the articular surface of the proximal pole and its tenuous blood supply. Ryu and Whipple (2017) have designed a fracture reduction and pin/screw guide to minimize fixation trauma, but disruption of the proximal pole articular surface remains an important concern. Attempts have been made to employ metal plate fixation for scaphoid waist fractures with very limited success (Stankovic and Burchardt 1993). The bone is small, the intra-articular space is very limited and screw fixation of a plate jeopardizes intraosseous circulation. Moreover, a plate applied to the surface of the scaphoid will cover much of the articular cartilage.

Proximal pole fractures: By definition, proximal pole scaphoid fractures jeopardize the terminal circulation within the bone. This makes accurate reduction of these fractures imperative to reduce the risk of avascular necrosis of the proximal pole and fracture nonunion. Gentle manipulation of the proximal fracture fragment under arthroscopic control through the radial 1–2 and 3–4 portals is most advantageous. Small-diameter K-wire fixation of the fracture fragment is not difficult with the wrist held in a flexed position. The wrist can be immobilized in flexion, leaving the fixation K-wires extruding through the capsule and skin, which will further stabilize the wires as they hold the short proximal pole fracture fragment in place for 3 to 6 weeks. Two to three K-wires are recommended for adequate stabilization of the proximal pole fragment.

Chip fractures: Chip fractures of the scaphoid usually represent avulsion fractures of the distal volar radial tubercle at the site of the scaphotrapezium ligament attachment. Even with malunion or nonunion, such fracture fragments are not in a position to interfere with intercarpal motion of the wrist, nor are they subject to impingement in wrist flexion or radial deviation. Therefore, they are of little significance ultimately, except as they may cause localized tenderness.

The attached ligament is not essential to wrist motion or stability. Its reattachment to the scaphoid is relatively insignificant. If the fragment is large enough, however, it may contain articular cartilage from the distal pole of the scaphoid that articulates with the trapezium. In time, nonunion of such a fragment may cause localized scaphotrapezium osteoarthritis. For this reason only, consideration may be given to arthroscopic removal of the fracture fragment. This may be accomplished with digital traction applied to the thumb and using two small portals into the scaphotrapeziotrapezoid (STT) joint just volar and dorsal to the first extensor compartment. There is no indication for attempting pin fixation of a scaphoid chip fracture. Thus, no treatment at all or arthroscopic fragment excision followed by immediate mobilization are the treatments of choice.

20.6 Grafting

Rarely is there a need to bone graft an acute scaphoid fracture. Severe fracture humpback deformity with crush comminution of the volar cortex of the scaphoid is the exception. Delayed fracture union, however, may necessitate osteoinductive grafting of a fracture site. Fractures treated nonoperatively or operatively should show definitive radiographic evidence toward union by 10–12 weeks, at the latest.

If a fracture line is readily visible at 12 weeks post injury, delayed fracture union is apparent and nonunion becomes increasingly probable. MRI scan or scintigraphy will usually indicate the potential circulation risk for a proximal pole fracture fragment. CT radiography will often indicate whether there is partial but incomplete bridging of the fracture site with calcified fracture callus. At 12 weeks, it may be premature to undertake vascularized bone grafting for an impending fracture nonunion. However, osteoinductive stem cell grafting is both plausible and convenient in such circumstances (Bajada et al. 2007; Conally 1998; Healey et al. 1990). In the author's experience, this can be accomplished under local or regional anesthesia by aspirating bone marrow from the iliac crest with a 14-gauge needle and injecting the aspirate into the scaphoid fracture site fluoroscopically with an 18-gauge needle. With appropriate immobilization, stem cells from autogenous bone marrow will facilitate the development of mature fracture callus, as is evident when monitored with serial radiographs. This callus will ultimately calcify to heal the fracture before mobilizing the the wrist, thereby obviating the surgical trauma associated with the harvest and placement of a vascularized scaphoid bone graft at the fracture site.

20.7 Conclusion

The advantages of arthroscopic reduction and fixation of scaphoid fractures include all of those that have been attributed to conventional internal fixation treatment. However, an arthroscopic surgical approach preserves the critical extrinsic and intrinsic ligaments for secure carpal stability and provides cosmetic advantages for the patient in lieu of open scaphoid fracture treatment. Arthroscopically assisted treatment should always be surveyed from the radiocarpal and the midcarpal portal vantages before concluding the procedure.

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Carpal Fractures Other Than the Scaphoid

21

T. L. Whipple

21.1 Introduction

Of the eight carpal bones, the scaphoid, or navicular, is the one that is fractured most often. However, fractures of the other seven carpals are not uncommon and should not be overlooked so as to avoid misdiagnosis or long-term complications resulting from inadequate treatment.

Fractures of non-scaphoid carpal bones occur most often in athletic injuries, motor vehicle accidents, or falls (Marchessault et al. 2009). Industrial crush injuries are also a significant but less common cause of carpal fractures. Because of the intricate, strong, and redundant intercarpal ligament complexes in the wrist and the numerous articular facets of the carpal bones, they are relatively well protected from traumatic fracture. Keyed together, the carpals are interdependent for joint stability. Except for the very mobile scaphoid, other carpal bones do not move excessively with respect to their adjacent carpals.

The relative stability of each carpal bone emphasizes four important postulates with respect to carpal fractures: (1) avulsion chip fractures resulting from strong ligament attachments to the bone are frequently encountered in carpal fractures; (2) high-energy forces are usually involved to produce non-scaphoid carpal fractures; (3) as carpal bones are intimately keyed together and are interdependently stabilized, non-scaphoid carpal fractures frequently portend other associated occult, carpal injuries including ligament tears, and articular cartilage injuries that may progress to carpal instability or intercarpal arthrosis if not recognized and treated; and (4) a high index of suspicion is necessary when localized wrist pain persists after trauma and the initial plain radiographs appear normal.

21.2 Anatomy

The eight carpal bones of the wrist are arranged in a proximal and a distal transverse row of four bones each. The proximal row consists of the scaphoid (not here discussed), lunate, triquetrum, and pisiform. Together, the proximal row articulates proximally with the radius and the triangular fibrocartilage complex and distally with the distal carpal row through six articular facets. The proximal row pronates on the radius in wrist flexion and supinates on the radius in wrist extension.

The distal carpal row consists of the trapezium, the trapezoid, the capitate, and the hamate. The distal row articulates distally with the five metacarpal bones through nine articular facets. The midcarpal space between the proximal and distal carpal rows accommodates a greater range

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of flexion and extension and a lesser range of radial and ulnar deviation.

The cortical surfaces of carpal bones are covered either with articular cartilage or with the soft tissue attachments of joint capsule or ligaments. There is little, if any, exposed bare cortical bone on the carpal bones. Therefore, virtually every fracture of a carpal bone involves an articular surface. Fracture lines that disrupt articular surfaces pose a risk of future development of post-traumatic arthrosis or arthritis solely due to the friction from a scarred articular surface. Anatomic reduction of carpal fractures is essential to minimizing the risk of arthrosis in the future.

Avulsion chip fractures of the carpal bones have attachment to intrinsic or extrinsic ligaments and may involve the articular cartilage surface of a carpal bone, as well. Chip fractures are usually associated with twisting or bending forces during an injury. If the associated ligament is critical to carpal stability, chip fractures usually will either heal or will develop a firm, fibrous nonunion when treated with simple cast immobilization of the wrist. Otherwise, if the chip fracture is small or the associated ligament is not critical for carpal stability, the fracture may be treated by excision of the chip fragment arthroscopically or with minimally invasive incision approaches.

Fractures of the bodies of these bones are usually associated with high-energy axial loads transmitted through the metacarpals or with crushing, blunt trauma applied in the sagittal or coronal plane. Twisting injuries, by contrast, pose greater risk to wrist ligaments, rarely causing fractures of the bodies of carpal bones.

Carpal fractures are commonly associated with carpal ligament injuries. The presence of a carpal fracture should always compel a suspicion of a “silent” ligament injury and potential carpal instability. Even though a non-displaced fracture may heal with simple cast immobilization, a thorough examination for associated point tenderness located other than directly over the fractured bone may require additional diagnostic investigation with MRI imaging. Optimal fracture treatment may entail surgical repair of associated ligament injuries and possible internal fracture fixation which would otherwise have been treated by simple casting. Non-scaphoid carpal bone fractures will be discussed in this chapter in their relative order of frequency of occurrence (Marchessault et al. 2009).

21.3 Triquetral Fractures

The triquetrum is the next most commonly fractured carpal bone, after the scaphoid. This bone may account for as much as 30% of all carpal fractures (Marchessault et al. 2009). Dorsal chip fractures of the triquetrum constitute up to 93% of all triquetral fractures. Hyperflexion of the wrist or flexion with radial deviation may cause avulsion of the dorsal triquetrum cortex where the dorsal radiocarpal ligament, the lunotriquetral ligament and the transverse dorsal intercarpal ligament attach. More rarely, extreme wrist extension and ulnar deviation may permit the proximal dorsal articular process of the hamate or the styloid process of the ulna to impact with the triquetrum dorsally and create a chip fracture.

Fractures of the body of the triquetrum can result from direct blunt trauma to the ulnar side of the wrist or from a crushing force applied dorsally or volarly impacting the triquetrum against the pisiform. Up to a fourth of the fractures to the body of the triquetrum, however, are seen in association with perilunate fracture dislocation injuries. Thus, a triquetrum body fracture associated with high-energy trauma should always evoke a high index of suspicion for perilunate dislocation or trans-scaphoid perilunate fracture dislocation, which is best appreciated on MRI scan images. Persistent ulnar wrist pain distal to the ulnar styloid process lasting longer than 3 weeks post trauma requires evaluation of the triquetrum by CT scan or MRI and should be differentiated from injuries of the triangular fibrocartilage complex.

Either chip or body fractures of the triquetrum in isolation can usually be treated successfully with cast immobilization. Displaced fractures of the body of the triquetrum may require either arthroscopic or open fracture reduction and internal fixation with pins or small compression screws. Arthroscopic surgical fixation requires attempted visualization of the fracture reduction through the midcarpal space, the radiocarpal space, or both, depending on the plane of the fracture. Most importantly, any fracture of the body of the triquetrum indicates assiduous assessment for possible perilunate fracture dislocation, utilizing MRI scan if necessary.

21.4 Hamate Fractures

It is estimated that approximately 7% of all carpal fractures involve the hamate bone. The body of the hamate articulates distally with the fourth and fifth metacarpals. Axial load through those metacarpals often causes dorsal fracture dislocation of the fourth or fifth carpometacarpal joints. This fracture is usually oriented in the coronal plane as the base of the fourth and base of the fifth metacarpals dislocate or sublux dorsally.

Less commonly, hamate fractures involve the hamular process, better known as the "hook" of the hamate. Fractures to the hook of the hamate can occur from falls on the outstretched hand. They also occur in the dominant wrist from ulnar deviations while gripping a racquet or in the non-dominant wrist from ulnar deviation when swinging a bat or golf club. Any of these mechanisms fracture the hook at its base where it emerges from the body of the hamate on the volar side.

Examination of hamate body fractures shows prominence of the fourth and fifth carpometacarpal joints dorsally with acute tenderness to palpation. In the absence of carpal-metacarpal fracture dislocation, fractures of the body of the hamate produce tenderness to palpation, pinching the volar and dorsal surfaces of the bone just proximal to the metacarpals.

A strong clinical sign of hamate hook fracture is either pain reproduced by volar compression of the hook of the hamate at the base of the palm or pain reproduced by resisted flexion of the proximal interphalangeal joints of the ring and little fingers. This latter sign is due to the flexor carpi superficialis, and/or flexor digitorum profundus tendinosis as these tendons articulate with the radial side of the hook of the hamate within the carpal canal. At times, these tendons may be abraded or ruptured by an acute or long-standing fracture nonunion. Pain that is aggravated by power grip should raise the index of suspicion for the flexor tendons to the ring and little fingers irritating the fracture at the base of the hamular process. Diagnostic radiographs require a carpal tunnel view of the wrist which projects the hamular process in profile. When a fracture is strongly suspected clinically but is not demonstrated by plain radiographs, CT scan in multiple planes or bone scintigraphy maybe helpful.

For non-displaced fractures of the body of the hamate, cast immobilization is usually a sufficient treatment. A short-arm cast that incorporates the ulnar two digits, with flexion at the metacarpophalangeal joint, is most comfortable and effective. Alternatively, for displaced or unstable fractures, open reduction and internal fixation with K-wires or compression screws are preferred for fractures of the body of the hamate. Neither sagittal nor coronal plane fractures of the body can be well-visualized arthroscopically, indicating that modality is of little use for evaluation or treatment of hamate fractures.

Fractures of the hamular process may heal with cast immobilization if they are non-displaced. Displaced fractures, however, or patients who desire the earliest possible return to sport or work requiring power grip are best treated with surgical excision of the hamular process (Marchessault et al. 2009). As the hook of the hamate forms the ulnar wall of the carpal canal and the radial wall of Guyon's canal, care should be taken to protect the flexor tendons and ulnar nerve during surgical procedures. Excision of the hamular process is the preferred treatment in cases of hook fracture nonunion.

21.5 Lunate Fractures

Fractures of the lunate may be due to either primary or secondary causes. Primary fractures are the results of any of three usual mechanisms: (a) axial load transmitted from the capitate through the lunate to the radius, (b) falls on an outstretched hand, or (c) catching a hardball in the palm with the forearm pronated and the wrist extended. Fractures of the body of the lunate are either compression fractures of the distal articular surface or linear fractures in the sagittal plane. If non-displaced and recognized early, these fractures may be adequately treated in a short-arm cast. If displaced, these fractures require either open or preferably arthroscopic reduction with K-wire stabilization. Arthroscopic treatment permits thorough assessment of the scapholunate and the lunotriquetral ligaments which are often injured concomitantly.

Commonly, fractures of the lunate consist of avulsion of the volar lunate pole by the strong volar radiolunate ligaments, frequently causing a DISI (dorsal intercalated segmental instability) with dorsal angulation of the lunate. Less often, the dorsal pole may be avulsed by the dorsal radiolunate extrinsic ligament which causes a VISI (volar intercalated segmental instability) with flexion angulation of the lunate. Encountering such fractures with VISI or DISI lunate posturing must raise strong suspicion of associated lunotriquetral or scapholunate intrinsic ligament tears, as well, which should be sought diligently and repaired, if possible.

Secondary fractures of the lunate—or disruption of the subchondral cortical bone caused by avascular necrosis (AVN) and structural bone weakness—are much more common, but sadly are not well understood. They may result from excessive compression load on the lunate between the ulna or radius and the capitate, as in ulna-positive variance deformities of the wrist. These lunate fractures are usually not due to acute trauma and are known as Kienböck's disease, about which much has been written and published.

Secondary lunate fractures, or Kienböck's disease, are categorized into four stages:

- Stage 1 shows no specific radiographic evidence of fracture, but scintigraphy or MRI will show compromised lunate circulation.
- Stage 2 shows a fracture, with or without comminution or fragmentation.
- Stage 3 fractures show the fracture with collapse of the height of the lunate.
- Stage 4 fractures have both associated collapse and arthrosis.

Patient symptoms vary widely with lunate fractures. The degree of pain or wrist dysfunction can bear very little correlation with the stage of the fracture. Stage 1 Kienböck's disease, without discernable disruption of the subchondral bone cortex, may be acutely and continuously painful and debilitating. Conversely, severe fractures with collapse may be minimally symptomatic.

Stage 1 fractures may be simply closely monitored for progression, or they may be immobilized with a short-arm cast. Stage 2 fractures usually are treated with some form of decompression or unloading procedure, ranging from percutaneous fenestration of the lunate to ulna shortening or radial lengthening, to radius incline osteotomy, and to arthroscopic resection of the head of the capitate (Leblebicioglu et al. 2003) or "decapitation of the capitate." All of these procedures have met with varying degrees of success and endorsement. It is sufficient to conclude that the precise cause of Kienböck's disease is not well understood and the optimal treatment approach is equally debatable.

Small chip fractures of the lunate are rare. They may involve either the volar or dorsal capsular attachments of the bone and are most commonly associated with trans-scaphoid perilunate dislocation injuries. They are easily reduced by wrist flexion or extension, respectively, and cast immobilization following surgical repair of the scaphoid fracture, the scapholunate, and/or the lunotriquetral ligament.

21.6 Trapezium Fractures

Trapezium fractures represent approximately 4–5% of all carpal bone fractures. The most commonly encountered fracture patterns are horizontal fractures, sagittal split fractures, dorso-radial chip fractures, volar ridge fractures, and comminuted fracture patterns. The volar ridge fractures often are caused by avulsion of a part of the ridge where the transverse carpal ligament attaches. These fractures are infrequently apparent on routine radiographs. They are best identified with carpal tunnel view radiographs when acute focal tenderness is found over the volar aspect of the trapezium in the absence of any history consistent with arthrosis of the adjacent first carpal-metacarpal joint.

Dorso-radial trapezium fractures appear radiographically as bone chips, which may be displaced as much as 3 mm. Dorso-radial fragments remain attached to the first metacarpal via the carpometacarpal ligament and displace dorsally or radially due to the pull of the abductor pollicis longus on the metacarpal. Internal fixation of these fracture fragments, either by open or percutaneous pinning methods, may forestay subluxation of the first metacarpal in the absence of basilar joint arthrosis. Diagnosis of trapezium fractures is suspected from a clinical picture of localized tenderness to palpation immediately distal to the scaphoid tubercle, a painful pinch test, or a positive "grind test," represented as pain when the examiner passively grinds the first metacarpal against the trapezium. There also may be pain with resisted wrist flexion due to the close proximity of the flexor carpi radialis tendon to the trapezium, if fractured.

Treatment of a trapezium fracture, if it is not displaced, may be sufficient with the application of a thumb spica cast. For a displaced fracture of any degree, open reduction and internal fixation are indicated. The surgical approach to the trapezium is made through a longitudinal incision at the junction of the palmar and dorsal skin demarcation over the first carpometacarpal joint. Fixation with screws provides secure fragment immobilization.

Fractures of the trapezium are frequently associated with fractures of the first metacarpal base (Walker et al. 1988). This accounts for the high association of post-traumatic basilar joint arthrosis ensuing after such fractures (McGurgan and Sulp 2002). Median nerve neuropathy and irritation of the flexor carpi radialis tendon have been reported in cases of missed or delayed diagnosis of trapezium fractures (Boulas and Milek 1990; Vigler et al. 2006).

21.7 Capitate Fractures

Only 1–2% of all carpal bone fractures involve the capitate, because this bone is so well protected in the center of the carpus. Capitate fractures are usually caused by high-energy forces to the wrist, such as crush injuries or in association with traumatic perilunate dislocation. In transverse waist fractures of the capitate, the proximal fragment may be malrotated 180°, requiring open reduction. Malrotation usually occurs with hyperextension of the wrist. Malrotation of the proximal capitate fragment associated with a scaphoid waist fracture is known as the "naviculocapitate fracture syndrome" or "scaphocapitate fracture syndrome" (Apergis and Palamidi 2013).

Two mechanisms are most commonly causative for capitate fractures: a direct posterior to anterior trauma or an axial load through the third metacarpal with the wrist in a flexed position. The latter can cause a capitate neck fracture, frequently associated with a fracture at the base of the third metacarpal. MRI scans are often used to evaluate the protecting extrinsic and intrinsic ligaments in high-energy injuries. Treatment of capitate neck fractures, if non-displaced, may employ K-wires passed either distal to proximal or proximal to distal percutaneously under fluoroscopic guidance or with arthroscopic assistance from the midcarpal portals. If the fragments are displaced, a headless compression screw may be used with an open, dorsal approach.

The capitate has a retrograde intraosseous circulation pattern similar to the scaphoid. Thus, capitate neck fractures, especially with malrotation of the proximal fragment, may develop avascular necrosis with collapse of the head of the capitate. Nonunions of capitate neck fractures occur in approximately 50% of such cases (Vigler et al. 2006).

21.8 Trapezoid Fractures

As with the capitate, the trapezoid is well protected in the carpus and represents less than 1% of carpal fractures (Boulas and Milek 1990). Fracture mechanisms usually involve axial load through the second metacarpal, as may occur in street fights or brawls. The trapezoid, in cross section through the distal carpal row, has a keystone shape between the trapezium and the capitate. Its dorsal surface is approximately twice that of its volar surface. Thus, from axial loading the trapezoid is more prone to extrude or dislocate dorsally than it is to fracture. When the bone does fracture, the most common pattern is a sagittal longitudinal split.

Treatment of trapezoid dislocation should employ longitudinal traction through the index finger and the second ray. The second metacarpal may be pinned to the third to maintain axial pressure relief from the trapezoid. Open reduction of the fracture fragments is usually necessary to reconstitute the keystone wedge. Fixation should employ either threaded K-wires or a headless screw. Treatment of trapezoid fracture nonunions should include fusion of the carpal to the second metacarpal base, which only compromises the palmar arch slightly.

21.9 Pisiform Fractures

The least commonly fractured carpal bone may be the pisiform. It is rivaled for the honor by the trapezoid which, curiously, is much better protected by surrounding bones than the pisiform. About half of all pisiform fractures are associated with other carpal fractures, which indicates that CT scan of the entire carpus is prudent when a pisiform fracture is identified on plain radiographs.

Plain radiographs alone may not reveal a fracture of the pisiform because of overlying bone shadows. When pisiform injury is suspected by clinical investigation, then CT scan of the carpus should be obtained early. Alternatively, the pisiform can be seen best on plain radiographs in lateral profile with a 30° supinated lateral projection.

The most common pisiform fracture patterns are transverse or sagittal splits and are caused often by falls on the outstretched ulnar base of the palm. Falls backward or to the side expose the pisiform to direct impact. Motor vehicle accidents and racquet sports are the next most frequent causes. The strong flexor carpi ulnaris tendon attachment to the pisiform and the abductor digiti quinti origin from its ulnar border influence the fracture pattern, whether a transverse or sagittal split.

Clinical examination finds very localized tenderness of the easily palpable pisiform, even in obese wrists. There is also pain on attempts to “shuck” the pisiform side to side or on resisted wrist flexion. The latter is due to the insertion of the flexor carpi ulnaris tendon on the pisiform. Distally, the pisiform is attached to the piso-hamate and the piso-metacarpal ligaments. The pisiform bone forms the lateral wall of Guyon’s canal, giving it intimate proximity with the ulnar nerve and artery. Fractures, even when occult, are often associated with ulnar neuropathy or pallor and claudication of the ulnar digits and the ulnar border of the hand.

Treatment of non-displaced pisiform fractures in patients with minimal physical activity demands may utilize a short-arm cast for 4 to 6 weeks to achieve fracture union. For more active individuals or for displaced fractures, however, surgical excision of the pisiform is a more expedient option for early return to function. Pisiformectomy requires an adequate surgical exposure to protect the ulnar nerve and artery in Guyon’s canal. After pisiform excision, the flexor carpi ulnaris tendon is sutured to the piso-hamate ligament, and the wrist is splinted in flexion for 2 to 3 weeks.

21.10 Conclusion

As noted in the preceding chapter, the scaphoid is by far the most frequently fractured carpal bone. Other carpal fractures do occur, but they may be occult and not readily apparent on plain radiographs. Clinical assessment requires a thorough physical examination of the wrist with assiduous focal palpation for tenderness using a blunt stylus, pencil eraser, cotton swab, or Q-tips (Lever Bros., Puerto Rico) for localization of point tenderness.

Non-scaphoid carpal fractures are frequently associated with intrinsic or extrinsic ligament injuries. A good knowledge of wrist anatomy and instability stress tests are most helpful. Most non-displaced fractures are treatable with short-arm casts or thumb spica casts. Displaced fractures usually require open reduction or, in select cases, arthroscopically assisted fracture reduction and internal fixation. Surgical excision of bone fracture fragments is expedient for early return to function in fractures of the hook of the hamate or the pisiform.

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22

Rehabilitation After Minimally Invasive Fixation of Hand Fractures

Tüzün Firat and Yasin Tunç

22.1 Introduction

Shorter recovery time, reduced scarring, and earlier return to activities of daily living are minimally invasive fracture fixation advantages (Capo 2007). These advantages also enable innovative rehabilitation approaches. To maximize the advantages of minimally invasive fracture fixation and to reduce potential complication risk, the physiotherapist should possess a good knowledge of hand and wrist anatomy (Zemirline et al. 2014).

Knowledge about bone and soft tissue healing biomechanics, fixation material loading properties, and surgical technical details are necessary to properly design rehabilitation protocols when minimally invasive fracture fixation is used (Scuderi and Tria 2009). Moreover, therapeutic exercises should be selected that recruit proprioceptive support from noncontractile (ligament) and contractile (muscle) tissues. Rehabilitation steps to reduce edema and pain, enhance proprioception, manage scar tissue, and optimize benefits associated with orthotic use are described in the following section.

22.2 Advantages of Minimally Invasive Procedures

Arthroscopy provides clear joint surface and surrounding capsuloligamentous structure visualization. This facilitates joint debridement, gap correction, and blood clot evacuation (Dei Giudici et al. 2016; Del Piñal et al. 2014). Arthroscopy also enables treatment of concomitant upper extremity lesions. Dei Giudici et al. (2016) identified ligamentous injuries in 68–98% of upper extremity joint cases and cartilage injuries in 32%. Approximately 21% of upper extremity joint injuries had an associated lesion (Dei Giudici et al. 2016). Moreover, arthroscopy is a good method to treat possible carpal instability problems (Smeraglia et al. 2016). The direct joint surface visualization arthroscopy provides better enables removal of osteochondral fragments that are not visible with conventional imaging methods. Volar plating prior to arthroscopy helps prevent excessive fracture traction during arthroscopy. Minimally invasive fracture fixation approaches, however, present several limitations. Fracture repair by arthroscopy requires a high degree of technical skill and has a prolonged and steep learning curve (Howells et al. 2008). Particularly in hand and wrist joints, small osteochondral fragment removal and implant placement in a narrow viewing window can be difficult, reducing fixation options (Dei Giudici et al. 2016).

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22.3 Assessment

22.3.1 Inspection and Palpation

Examining hand posture should be the first clinical assessment step. Synchronous movement between the forearm and proximal carpal row, metacarpals, and phalanges should be evaluated in addition to inspection of web-space widths and transverse and longitudinal palmar arch congruence. Following this, palpation of the carpals, dorsum of the hand, metacarpals, dorsal and volar wrist capsule, and phalanges is performed. Lastly, temperature of the entire hand should be evaluated (Dincer and Samut 2014).

22.3.2 Pain

Pain is a multifaceted symptom with characteristics and duration that should be comprehensively and precisely assessed. Pain threshold may also be used as a guide to functional range of motion, joint loading, and safe therapeutic exercise intensity levels (Klein 2014).

22.3.3 Range of Motion

Range of motion of the entire upper extremity including the cervical spine region and scapulothoracic articulation should be evaluated. Proper goniometric methods are necessary to achieve accurate measurements. A digital goniometer should be used for finger motion assessment. Additionally, sensor-based motion capturing systems can be helpful to measure both integrated and isolated upper extremity joint function.

22.3.4 Edema

Although the immobilization duration is generally shorter after minimally invasive fracture fixation, edema is usually present (Orbay and Fernandez 2004). Visual inspection generally is the first step in edema volume assessment. After suture removal, volumetric assessment can be used to provide more objective hand and wrist edema measurements. Systematic postural and behavioral factors that may contribute to edema development should also be considered.

22.3.5 Muscle Testing

Muscle testing can be performed when fracture site stability has been restored. The extensor pollicis longus, extensor pollicis brevis, and abductor pollicis longus of the thumb, and flexor digitorum superficialis and profundus of each finger should be evaluated to better determine specific tendon normalcy in addition to more composite standard manual muscle testing procedures (Kendall et al. 2005).

22.3.6 Grip and Pinch Strength

Grip strength is accepted as a standard hand function test. Several devices can be used for objective grip strength measurements. Standard grip strength measurements are performed with the shoulder in adduction, with the forearm in neutral position, and with the elbow at 90° flexion. Adjustable handle spacing provides an adaptation to accommodate hand position when gripping is impaired. The healthy hand should serve as a control for strength loss estimates. An average of three measurements for each hand is recommended (Taylor and Shechtman 2000). There are three types of pinch tests: three-fingered pinch, lateral or key pinch, and tip pinch. If possible, all types should be assessed. As with grip strength measurements, an average of three trials should be recorded, and comparisons can be made with the opposite hand (Klein 2014).

22.3.7 Functional Tests and Scales

In addition to grip and pinch strength assessments, coordination tests provide information about injured hand function. These tests require standardized test equipment and strict criteria. Proper complementary upper extremity function assessments and sequences should be followed. Some of these tests include the Jebsen Taylor Hand Function Test, Minnesota Test, Purdue Pegboard Test, Crawford Small Parts Dexterity Test, O'Connor Peg Board Test, and Nine Hole Peg Test. Self-reported scales include the Disabilities of the Arm, Shoulder, and Hand (DASH) test; Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) test; Patient-Rated Wrist Evaluation (PRWE); and Michigan Hand Questionnaire (Heyde and Droege 2007).

22.4 Rehabilitation

22.4.1 Edema Management

Minimally invasive surgical techniques decrease postoperative edema and reduce wrist stiffness. Edema control during postoperative hand rehabilitation is essential (Artzberger 2007). Edema management can be provided by a combination of elevation, active-controlled motion, and compression during tissue healing. During the acute phase, elevation of the affected upper extremity above the heart facilitates lymphatic drainage via increased hydrostatic pressure along the lymphatic trunks. Elevating the affected upper extremity with pillows is especially important during the initial two postoperative weeks (Moscony 2013). The intermittent compression associated with rhythmic muscle activation from active exercises stimulates the venous and lymphatic system pump (Rodrick et al. 2004). Provided that fracture fixation is maintained and neuromuscular activation is restored, active and resistive exercises can also be used to control edema. A self-adherent elastic bandage is commonly used for edema control. The physiotherapist must be careful to apply the bandage lightly from distal to proximal, as it must not be too tight. Patients must be instructed how to carefully self-assess any signs of a tight bandage especially at night (e.g., cyanosis, cold, or numb fingertips) (Artzberger 2007). Active range of motion exercises facilitates tissue fluid movement and edema control, prevents tendon adhesions, and increases joint mobility. The physiotherapist and patient must be careful while advancing the therapeutic exercise program as excessive tissue overload may increase pain and edema (Villeco et al. 2002).

22.4.2 Proprioceptive Input

Neuromuscular rehabilitation varies depending on the nature of the hand or wrist injury, the type of surgery, and the primary rehabilitation program purpose. Postoperative rehabilitation programs include different therapeutic exercises used to train both conscious and unconscious proprioception. For this training, varying combinations of isometric, concentric, eccentric, isokinetic, co-activation, and reactive muscle activation exercises may be used (Hagert 2010). Proprioceptive training is initiated early after surgery. When immobilization is a necessity, mental imagery during grasping, writing, and pinching tasks can help maintain the cortical activation pathways necessary for future function (Chaturvedi et al. 2017). Reeducation of conscious proprioception can be initiated early post-surgery. Physiotherapy should stimulate joint and cutaneous mechanoreceptors to improve kinesthesia and joint position sense.

Massaging, brushing, and banding are commonly used simple approaches to stimulate cutaneous mechanoreceptor responses (Hagert et al. 2005). Isometric exercises of the wrist and fingers can be used to facilitate voluntary muscle activation by stimulating the motor cortex and descending neuromuscular control pathways (Figs. 22.1). Similarly, isometric exercises at the hand and wrist have an important role in wrist proprioception reeducation (Garcia-Elias 2008) (Figs. 22.2 and 22.3). The use of a small therapy ball can stimulate wrist flexor and extensor co-activation and improve wrist motion coordination (Woodley et al. 2007) (Fig. 22.4).

Unconscious neuromuscular sensation is the ability to achieve appropriate posture and maintain joint stability by feed-forward control of muscles around a joint (Konradsen 2002). Unconscious proprioception plays a primary role in joint stabilization. In unconscious neuromuscular training, the goal is to achieve smooth and balanced wrist motion and to develop the muscle movement needed for joint protection while avoiding excessive neuromuscular activation or co-activation levels. During this training, perturbation exercises and reactive muscle activations are utilized (Fitzgerald et al. 2000). This mechanism helps stimulate unconscious proprioception reeducation via reactive muscle activation responses (Balan and Garcia-Elias 2008). Postoperative immobilization after wrist injuries not only negatively affects wrist afferent stimulation, but visual awareness of the skin as well. The influence of visual awareness

Fig. 22.1 Proprioceptive hand and wrist training using a wobble board

Fig. 22.2 Finger metacarpophalangeal joint flexion, interphalangeal joint extension, and thumb adduction while grasping a paper towel to improve palmar interosseous and lumbrical muscle function

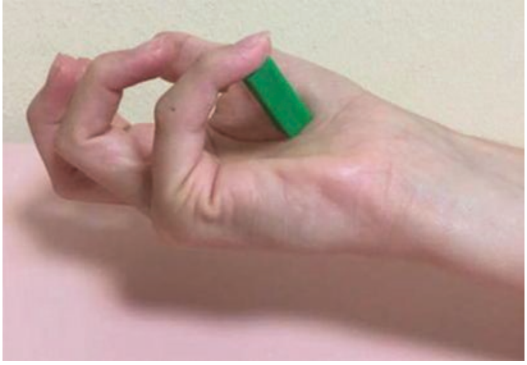

Fig. 22.3 Isometric strengthening of the fifth flexor digitorum profundus muscle with using a rubber compression block to improve power grip via activating fifth finger. It also promotes fifth finger coordination

Fig. 22.4 Dynamic stabilization exercise using a proprioception ball to stimulate coordinated wrist flexor and extensor function

Fig. 22.5 The injured hand is positioned in a mirror box while the healthy hand is positioned in front of the mirror. The patient can "trick" the brain into believing that the reflected image of the healthy hand in the mirror is the injured hand. This facilitates the neural network regeneration needed for effective hand-brain coordination

reduces the conscious awareness of the wrist (Maravita et al. 2003). For this reason, it is important to develop conscious wrist proprioception awareness. Reeducating proprioceptive awareness with appropriate physiotherapy facilitates afferent neural pathway regeneration at the injured wrist. This helps to improve unconscious proprioception in the long term (Myers and Lephart 2000). Mirror therapy improves patient proprioception awareness after wrist surgery. The patient positions the healthy wrist in front of a mirror to produce an illusion of injured wrist motion. As the healthy wrist moves, the injured wrist attempts to replicate the movement behind the mirror (Altschuler and Hu 2008) (Fig. 22.5).

22.4.3 Scar Tissue Management

Effective scar tissue management includes scar mobilization, scar retraction, and vibration application. Scar mobilization includes deep massage horizontally across the full extent of the scar (Roseborough et al. 2004). Scar retraction can be performed to prevent soft tissue adhesions. With scar retraction, the patient performs active range of motion, while the physiotherapist mobilizes the skin in the direction opposite to the motion (Chang and Ries 2001). After arthroscopic surgery, the portals should be mobilized to prevent capsular adhesions especially around the wrist. At approximately 8 weeks postsurgical wound closure, scar remodeling interventions using a variety of silicone sheets or gels, oils, lotions, and creams may be used daily in combination with massage therapy and static or dynamic splints (Berman et al. 2007). When intense postsurgical scarring occurs, it is difficult to mobilize both the involved joints and the tendon. In these situations, therapeutic ultrasound may be beneficial. Therapeutic ultrasound provides deep heating, elevating soft tissue temperatures, and increasing scar water content, thereby improving soft tissue elasticity and extensibility (Michlovitz 2002). Painful or hypertrophic scars can be treated with iontophoresis using a dexamethasone sodium phosphate and sodium chloride solution (Bélanger 2010).

22.4.4 Pain Management

Pain is a common postsurgical problem that negatively affects quality of life (Astifidis 2007). Non-pharmacological modalities including transcutaneous electrical nerve stimulation (TENS), high-voltage pulsed galvanic current (HVPGS), magnetotherapy, massage, biofeedback, mirror therapy, and desensitization can be used for pain management (Fig. 22.6). With limited supportive research evidence, physiotherapists use thermal agents either before or after therapeutic exercise programs and activities to improve joint function. The application of thermal agents may induce joint movements that result in improved connective tissue extensibility, increased joint mobility, and decreased pain (Fedorczyk and Barbe 2002). TENS has been shown to decrease postoperative pain. TENS is

Fig. 22.6 Through deep tissue penetration, magnetotherapy promotes tissue healing and pain relief. Electrical current induces the ionic flow that enhances cytoprotection, cellular restoration, growth factor synthesis and ultimately, tissue healing

regarded as a relatively inexpensive, safe, and easy-to-operate, noninvasive pain management modality with few side effects (Moscony 2007; Sluka and Walsh 2003). In this regard, TENS selectively activates non-noxious afferent cutaneous nerve fibers which inhibit the transmission of nociceptive information to the spinal cord (i.e., segmental modulation) (Fedorczyk 1997). This modality uses externally applied electrical stimulation with surface electrodes. The electrodes may be placed close to the surgical site or along a peripheral nerve. The frequency should be set at 60–120 Hz, the pulse duration should be set between 50 and 100 μs, and it may be effectively used between 15 min and 24 h daily as needed (Walsh et al. 2009).

Patients should be advised to avoid extreme range of motion or functional activities that aggravate surgical site pain. It may not be possible to avoid all activities of daily living; therefore, instruction on how to modify these activities may help minimize pain. Orthoses or limb positioning may be used to offer intermittent rest to painful tissues, but painless, controlled range of motion exercises should be performed throughout the day. Physiotherapists may use transdermal drug delivery to treat pain. Iontophoresis and phonophoresis can be used to deliver analgesics and anti-inflammatory agents transdermally.

22.4.5 Manual Therapy

Although the scientific support is not strong, there has recently been an increased interest in the use of manual therapy for hand rehabilitation. Many approaches have been developed for immediate pain relief. Their mechanical effects, efficacy, and mechanisms have been reported in a systematic review (Hertling and Kessler 2006). Manual therapy approaches are important treatment components for wrist and finger injury rehabilitation. Improved knowledge of tissue healing, connective tissue load, and treatment volume limits are needed (Piligian et al. 2000). Joint stiffness reduction is one of the primary reasons for manual therapy use. It should be emphasized that manual therapy is a complementary element to other approaches including orthotics, therapeutic exercise, edema management, and taping (Kisner and Colby 2012). The selection of a particular manual therapy technique is based on physiotherapist preferences, training, biases, and previous experience. Additionally, the specific surgical procedure that was employed may contribute to rehabilitation technique and target tissue determination. For example, after wrist arthroscopy, portals should be kept as mobile as possible to prevent capsular fibrosis. In some cases manual therapy approaches may be used at more proximal areas including the cervical spine, scapulo-thoracic articulation, and the glenohumeral joint. Manual therapy approaches after minimally invasive fracture fixation surgery should always be performed gently to maintain fracture stability. Higher forces should be avoided to avoid reinjury especially after metacarpal fractures (Skirven et al. 2011). As a guide, the following steps can be used:

Step I: Small amplitude movements performed at the beginning of the available range of motion
Step II: Large amplitude movements performed in the resistance-free part of the available range of motion
Step III: Large amplitude movements performed up to the limit of the available range of motion
Step IV: Small amplitude movements performed up to the limit of the available range of motion

Step V: Small amplitude, high-velocity thrusts performed usually at the end of the available range of motion

Capsular tightness and joint stiffness may be the result of minimally invasive fracture fixation surgery (Scuderi and Tria 2009). To overcome this, joint traction and segmental gliding based on the convex-concave rule can be used in conjunction with the aforementioned steps. Radiocarpal, carpometacarpal, metacarpophalangeal, proximal, and distal interphalangeal joint mobilization using steps I, II, or III are generally recommended. Steps IV and V are not preferred during the early healing phases. It should be noted that appropriate manual therapy application should also have positive pain reduction effects.

22.4.6 Orthotics

Orthotic use after minimally invasive fracture fixation surgery can support fracture stabilization, facilitate bone healing, enhance soft tissue remodeling, decrease pain, enable earlier safe joint mobilization, improve function, correct alignment, and stretch contractures. Shear forces applied near the fracture line should be avoided (Lohman 2008; Strickland 2005). The presence of edema should be considered before orthotics are used (Fess and McCollum 1998). Due to its adverse effect on proprioceptive input, orthosis usage time should be limited to the minimal time perceived necessary to optimize the positive effects. In the case of edema, orthosis application should be performed after the edema has been effectively managed (Fig. 22.7).

Fig. 22.7 Wrist splint for supporting fixation

22.5 Therapeutic Exercise Regimes

Therapeutic exercise regimes should be comprehensively planned. Proprioceptive treatment is an important early step. In addition to visual input, mental imagery methods also can be applied. Thus, cortical neural pathways can be preserved until active motion can be initiated. The aims of the therapeutic exercise program should be to improve soft tissue elasticity and mobility, to preserve or improve tendon excursions, and to recover muscle and hand function. Early controlled and protected motion limits should be known (Smith et al. 2004). Early controlled motion represents the safe, allowable motion for the involved or previously immobilized joint (Souer et al. 2011).

22.5.1 Tendon-Gliding Exercises

Tendon-gliding exercises, which can be considered examples of early controlled motion, provide a safe approach at therapeutic exercise program initiation. They also contribute to improve affected joint passive range of motion. In phalangeal fracture cases, these exercises are essential for preserving flexor tendon system gliding function. Active wrist exercises can also be implemented with tendon-gliding exercises to facilitate tendon excursion (Rozmaryn et al. 1998) (Fig. 22.8).

22.5.2 Grip and Pinch Exercises

Using different size blocks, pinching exercises can be initiated. Different block dimensions and densities allow the thumb and index fingers to apply compression forces through varying ranges of motion against varying resistances. Blocks can

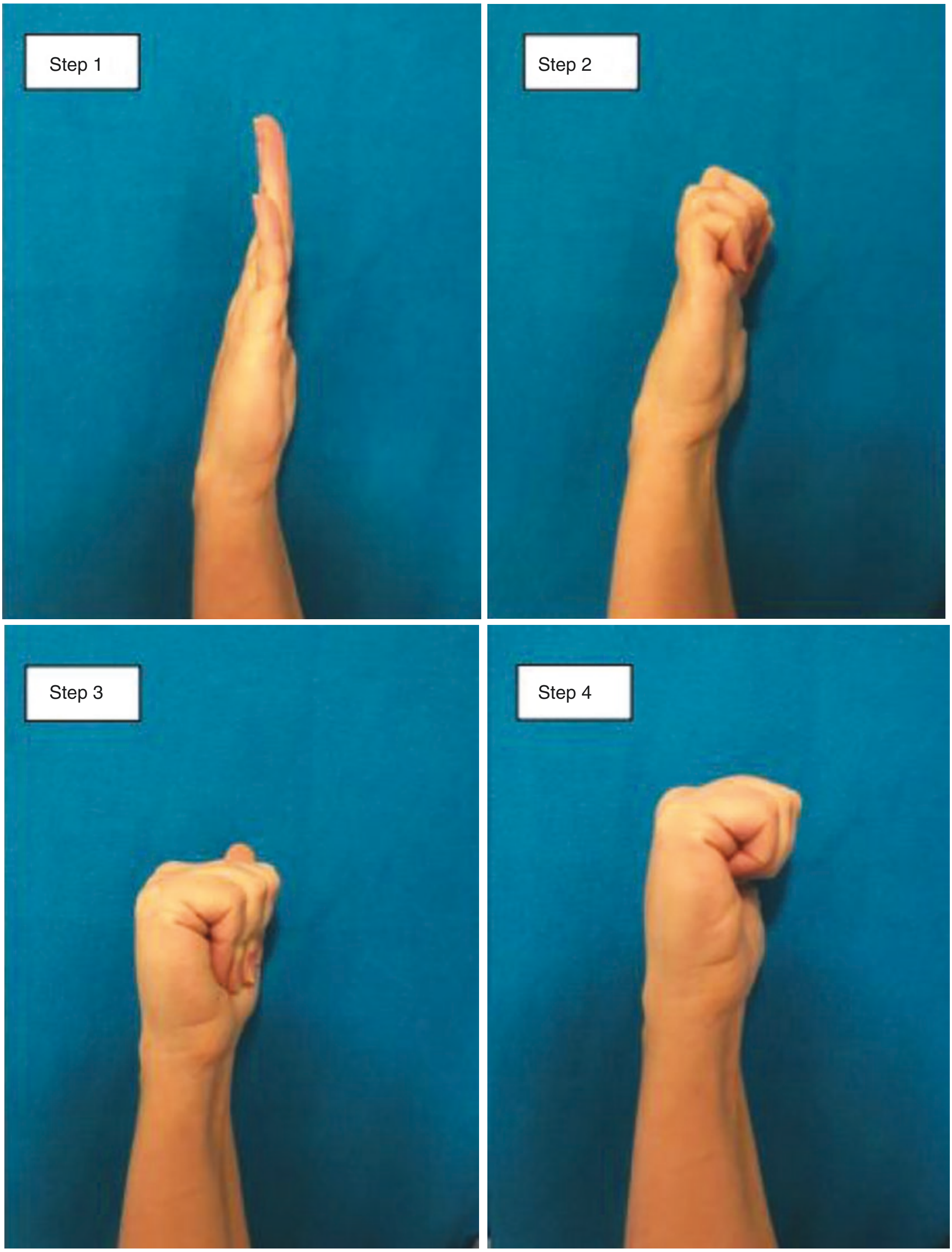

Fig. 22.8 Tendon-gliding exercises: Step 1: Straight, Step 2: Hook Fist, Step 3: Straight fist, Step 4: Full fist. This active therapeutic exercise series promotes tendon gliding especially in phalanx fracture treatment

also provide resistance for thenar muscle exercises (Figs. 22.9 and 22.10). These therapeutic exercises provide a relatively safe early intervention prior to transitioning to other more intense functional hand and wrist strengthening exercises (Grenier et al. 2016; Hammond and Prior 2016).

Fig. 22.9 Pinching exercise using a rubber compression block for isolated finger strength, flexibility, and coordination. This exercise enhances thenar muscle isometric activation and facilitates dynamic thumb stability

Fig. 22.10 Gripping exercise to increase hand strength. This resistance training device has five color coded resistance levels (yellow = low, black = high). Distal and proximal phalanxes gripping exercises can be performed separately (CanDo Digi-Flex®, Digi-Flex, Hockley, England, UK)

22.5.3 Muscle Reeducation

Following surgery immobilized tissues quickly lose proprioceptive acuity, mobility, and functional capacity. Neuromuscular electrical stimulation can be used for reeducation of hypotrophied muscles. This modality can also be used effectively at the dorsal and palmar interosseous muscles using two monopolar electrodes. High-voltage pulsed galvanic stimulation and asymmetrical biphasic currents between 200 and 400 μs duration time is recommended (Stralka et al. 1998). Patients should attempt to volitionally activate their muscles simultaneously with electrical current and visual feedback (Fig. 22.11).

Fig. 22.11 Neuromuscular electrical stimulation for dorsal interosseous muscle reeducation using two motor-point electrodes

22.6 Conclusion

Advantages of minimally invasive fracture fixation surgical procedures include reduced tissue damage, improved joint alignment, and earlier mobilization. These advantages serve as the foundation for rehabilitation strategies that include sensory input, soft tissue mobilization, and muscle reeducation. With consideration for the restrictions associated with the specific pathology and surgical intervention, joint mobilization protocols should be implemented as early as possible to enhance functional recovery.

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Part IV

Arthroscopic Management of Pelvis and Hip Fractures

23

Arthroscopic Management of Acetabular Fractures

Eyal Amar, Zachary Tuvya Sharfman,
David Edward Lebel, and Ehud Rath

23.1 Introduction

The indications for hip arthroscopy and the technical competency of hip arthroscopy specialists have increased substantially, expanding the potential for this expertise into the arena of trauma surgery. The advantages of arthroscopic osteosynthesis for acetabular fracture fixation as compared to open techniques are the minimally invasive nature, the magnified vision of the joint- and weight-bearing surfaces, and the ability to treat concomitant intra-articular pathology. Other advantages may include better cosmetic outcomes and cost-efficient outpatient surgery. The disadvantages of these procedures are that they are technically demanding, with long learning curves, with limited fixation possibilities, and with increased risk of fluid extravasation in the trauma setting. This chapter introduces the current indications, key concepts, surgical techniques, and utility of arthroscopic osteosynthesis of acetabular fractures.

23.2 Acetabular Fractures

Acetabular fractures most commonly occur as the result of high-energy blunt trauma in young patients or as the result of low-energy falls in the elderly population. The location of these fractures is most often on the posterior wall of the acetabulum. However, the pathoanatomy of these fractures depends on the force vector/direction and the position of the femoral head at the time of injury. Acetabular fractures are generally classified by the Judet and Letournel classification, which describes five basic and five associated fracture patterns. Nonoperative management of acetabular fractures is generally reserved for (1) minimally displaced fractures, <2 mm; (2) for fractures where the femoral head retains its congruence with the weight-bearing roof of the acetabulum; (3) for congruent fractures at both columns; and (4) in patients with contraindications to surgery, such as obesity or other serious diseases.

Operative management of acetabular fractures is indicated in patients with (1) roof displacement >2 mm, (2) posterior wall fractures involving >40–50% of the wall, (3) loose bodies, (4) marginal impaction, and (5) irreducible fracture dislocation. In these cases, open reduction and internal fixation (ORIF), with acute total hip arthroplasty, and percutaneous fixation with column screws are often employed. Recently, hip arthroscopy has also been increasingly employed to treat

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acetabular fractures or as an augment to open surgery for acetabular fractures (Gotz and Schulz 2013; Kim et al. 2013; Niroopan et al. 2016; Yamamoto et al. 2003; Yang et al. 2010).

23.3 Current Role of Hip Arthroscopy in the Treatment of Acetabular Fractures

In a systematic review of hip arthroscopy in the setting of acetabular fractures, Niroopan et al. (2016) established six indications for hip arthroscopy in the presence of trauma. The indications are (1) bullet extraction, (2) removal of intra-articular loose bodies, (3) femoral head fracture fixation, (4) arthroscopic-assisted or all-arthroscopic acetabular fracture fixation, (5) treatment of labral pathology, and (6) debridement of a ligamentum teres avulsion. Further potential indications for hip arthroscopy in the setting of trauma include arthroscopy as a diagnostic tool, especially in the case of unknown pain after fracture fixation. These applications are outlined in this chapter with examples of their uses, preferred techniques, and published or proposed cases of their applications.

23.3.1 Removal of Fragments

Perhaps the most utilized application for hip arthroscopy in the presence of acetabular fractures is the removal of loose bodies. The incarceration of loose bodies or bony fragments between the acetabulum and femoral head poses the risk of damaging the articular cartilage. Loose bodies may result from non-penetrating trauma such as bone fragments arising from a dislocation, or alternately loose bodies may result from direct penetrating trauma, such as in the case of a bullet or shrapnel.

In patients with a hip dislocation, multiple failed reduction attempts should raise the suspicion of a loose body in the joint. Concentric reduction of the hip may not be possible in the presence of a loose body, and sustained loose body pressure against the femoral head or acetabular dome may result in articular cartilage damage. Thus, intervention may be necessary to remove loose bodies and allow for hip reduction. Initial loose body management consists of traction applied to the leg in order to distract the joint surfaces and prevent articular cartilage damage. Definitive management will typically include loose body removal with or without fixation of the associated injuries.

Techniques to achieve removal of debris in the hip joint are open surgical extraction, fluoroscopically guided percutaneous techniques, and hip arthroscopy (Marecek and Routt 2014). Although technically challenging, hip arthroscopy provides a safe alternative to open surgery for the removal of loose bodies. Depending on the location of the loose body within the hip, different techniques can be employed to dispose of the debris. Small fragments, i.e., those less than 5 mm in size, are amenable to washout under suction. This can be achieved with a 5.5 mm arthroscopic cannula and the outer sleeve of a 5.5-mm-long abrader burr (Smith & Nephew, Andover, MA) (Fig. 23.1).

In the central compartment, manual extraction with a grasper or shaver is possible in addition to suction removal though the cannula. The removal of large osteochondral fragments from the central hip joint compartment can be exceedingly challenging. In these cases the surgeon can circumvent the limitations of hip distraction and the hip's anatomy with curved pituitary graspers. When fragments are attached to the surrounding soft tissues of the hip joint (i.e., the ligamentum teres, capsule, or labrum), an arthroscopic scissors or a curved hooked tip radiofrequency instrument can be used to facilitate the detachment and removal of the fragments.

In the case of loose bodies in the peripheral compartments of the hip joint, additional portals such as the posterolateral portal can be used to facilitate access for removal (Ilizaliturri et al. 2005). Alternatively, fragments that are located medially in the hip joint may be suctioned laterally and then removed. Another technique described in the literature is to employ a nitinol

Fig. 23.1 (Reproduced with permission) A cannula can facilitate removal of free bodies smaller than 5 mm. A 5.5 mm cannula (**a**); the outer sleeve of a 5.5-mm-long abrader burr (**b**); and a changing rod inserted into a suction tube, which allows the tip of the soft tube to be directed to the desired intra-articular location (**c**)

Fig. 23.2 (Reproduced with permission) The nitinol stone retrieval basket securely snares the loose body

stone retrieval basket (Boston Scientific, Marlborough, MA). This device was originally designed for the removal of ureteral stones but has proven effective for the removal of loose bodies in the hip (Rath et al. 2014). The device is inserted through a cannulated rod that enables directional control of the internally delivered basket device. Once the basket is properly aligned with the fragment, the internal basket is advanced to snare the loose body, facilitating removal over a slotted cannula (Smith & Nephew) (Fig. 23.2).

23.3.2 Fracture Fixation

There is a scarcity of literature in terms of acetabular fracture fixation using arthroscopic techniques. What has been published consists largely of case reports describing surgical techniques (Kim et al. 2013; Niroopan et al. 2016). Although the indications for hip arthroscopy continue to grow, with respect to acetabular fractures, the indications are narrow. Only minimally or moderately displaced acetabular fractures may be amenable to definitive treatment with hip arthroscopy. The angle of the fracture must be within a plane that allows for insertion of percutaneous or transportal screw insertion. In order to facilitate instrument maneuverability, hip distraction is necessary; therefore, acetabular fractures in patients with a stable pelvis amenable to traction against a perineal post are potential candidates for arthroscopic fixation. Clinical factors such as body habitus must be considered, as the arthroscopic instrumentation may not be of the appropriate length.

Arthroscopic-assisted fixation of the anterior pelvic column using percutaneous screw fixation was described by Yang et al. (2010). The authors implemented standard arthroscopic portals to approach this case. First, inspection and irrigation of the joint were carried out, followed by fracture identification. Then, fluoroscopic guidance was used to make a small incision medial to the level of the radiologic teardrop. Soft tissue dissection down to the bone was achieved, and a guidewire was drilled from just medial to the radiologic teardrop at a 75° angle, 5° in the transverse plane, and at a 20° angle, 2° to the sagittal plane. An AP fluoroscopic view was used while finding the entry point for the guidewire, and the obturator foramen view was used to control guidewire progression through the anterior column of the pelvis. The arthroscope was then inserted into the anterolateral portal to monitor that the screw did not penetrate the acetabulum during fixation over the guidewire. Additionally, an arthroscopic probe was used in the acetabular dome to help achieve reduction during lag screw placement. After guidewire placement, a drill was placed over the guidewire to create the path for the lag screw, and the screw was placed (Fig. 23.3). Arthroscopic visualization of the acetabular dome was maintained throughout the procedure to insure satisfactory alignment and fixation of the fracture and to verify that the screw did not penetrate the integrity of the acetabulum (Fig. 23.4).

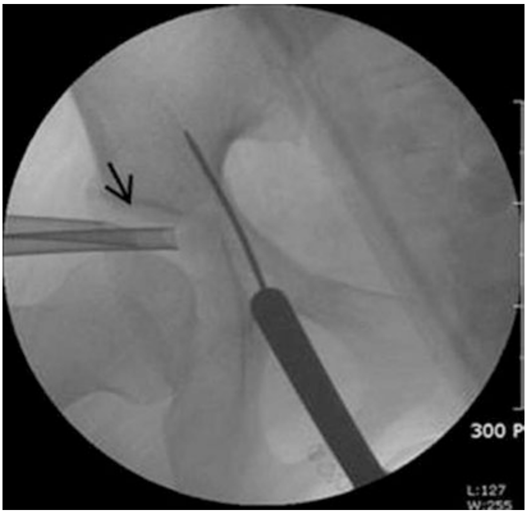

Fig. 23.3 (Reproduced with permission) Retrograde guidewire placement into the anterior column of the right hip in case 1. The entry point was just medial to the teardrop. Drilling over the guidewire was performed under direct visualization through the hip arthroscope through the anterolateral portal (arrow)

Kim et al. (2013) reported on two cases of arthroscopic reduction and internal fixation of acetabular fractures. In the first case, the definitive treatment was achieved using arthroscopic reduction and internal fixation alone, and in the second case, an additional plate and screws were placed on the iliac wing via an open approach. The surgeons describe reducing a displaced posterior wall fracture using two 1.1 mm K-wires and two 4.0 mm cannulated screws. In the second case, they describe using 3.5 mm cortical screw to fixate and compress an anterior column acetabular fracture in the AP plane.

Hip arthroscopy was also used as an adjunct to open reduction and internal fixation of an acetabular fracture. During screw insertion, the authors used direct arthroscopic visualization to confirm fracture reduction and compression (Gotz and Schulz 2013).

23.3.3 Diagnosis

Arthroscopy allows for direct visualization of the hip joint, making it an important diagnostic tool. Acetabular fractures are often caused by high-energy traumatic mechanisms. These injuries commonly result in concomitant injury to soft tissues about the joint and extensive intra-articular pathology. The injuries may range from loose bodies to labral tears, step deformities, and osteochondral lesions. As plain film radiographs and CT imaging may underestimate the true incidence of many of these pathologies, arthroscopy is a powerful tool to establish a correct diagnosis (Khanna et al. 2014).

The most common hip injuries following high-energy trauma are acetabular fracture, hip dislocation, ligamentum teres injury, loose body, cartilage injury, and labral tear (Byrd and Jones 2004). These pathologies are potential precursors for early degenerative processes in the joint that may be amenable to hip arthroscopy (Kashiwagi et al. 2001; Mullis and Dahners 2006; Philippon et al. 2009).

Philippon et al. (2009) studied the arthroscopic findings in 14 professional athletes after trau-

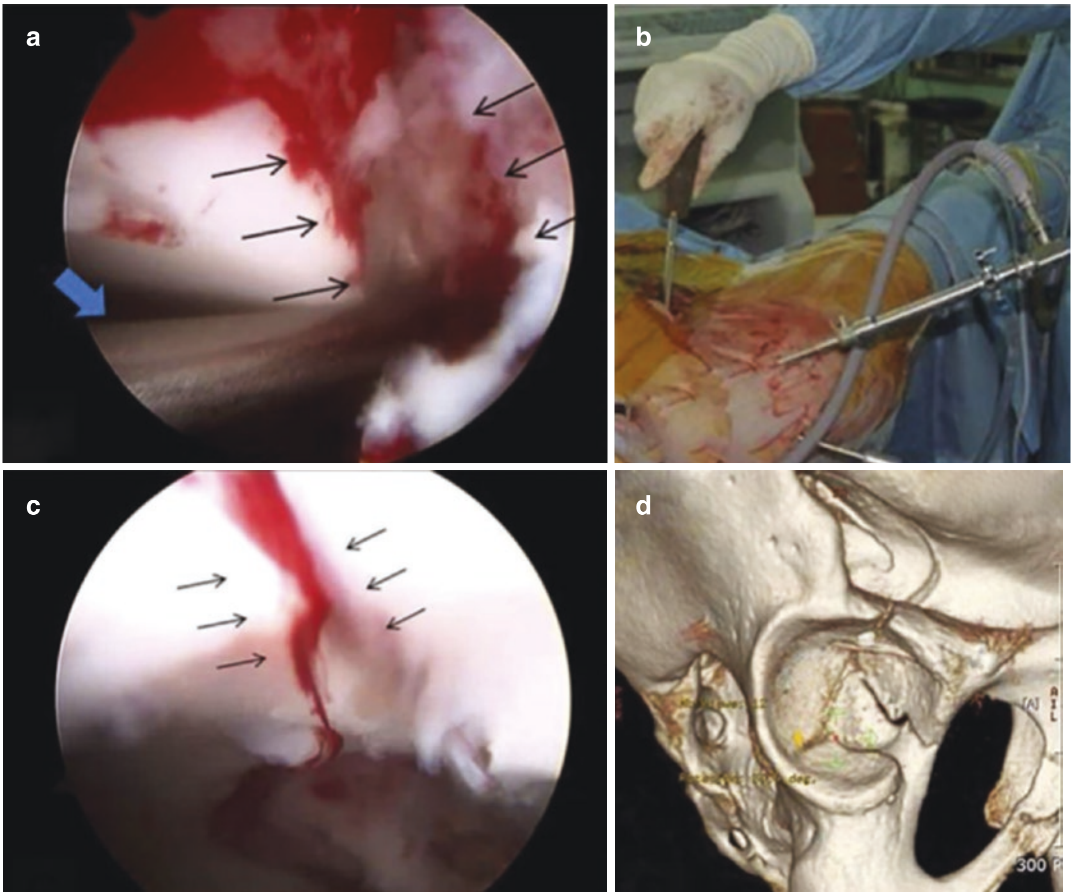

Fig. 23.4 (Reproduced with permission) (**a**) Arthroscope through anterior portal viewing fracture site (black arrows) after debridement of fracture margins. An arthroscopic hook (blue arrow) through the anterolateral portal was used as a reduction tool during compression of the fracture gap. (**b**) Arthroscopy of the hip using anterior, anterolateral, and posterolateral portals. It should be noted that the anterolateral portal was used for viewing and the posterolateral portal for outflow. (**c**) Reduction of intra-articular fracture site (arrows) was confirmed intraoperatively under direct visualization by hip arthroscopy. (**d**) Postoperative computed tomographic imaging showing anatomic reduction of the articular fracture site

matic hip dislocation. The authors observed chondral injuries and labral tears in all of the study subjects. Moreover, 11 of 14 subjects also had loose bodies within the joint. Ilizaliturri et al. (2011) conducted a similar study, where 17 patients who sustained posterior hip dislocations underwent diagnostic and therapeutic arthroscopy. Chondral injuries and labral tears were found ubiquitously in all 17 patients, and 14 of 17 patients were also found to have intra-articular loose bodies.

Early identification and management of traumatic hip pathologies may prevent the development of irreversible sequelae such as early post-traumatic osteoarthritis. The rate of post-traumatic arthritis has been reported as high as 24% at 5 years post-traumatic posterior hip dislocation without associated fracture (Upadhyay et al. 1983). In patients who sustained complex injuries or fractures in addition to posterior hip dislocation, the prevalence of post-traumatic arthritis increases to 54% (Armstrong 1948; Upadhyay et al. 1983).

23.3.4 Direct Acetabular Visualization to Prevent Screw Penetration

One well-known complication of pelvic fracture fixation is screw penetration into the acetabulum (Byrd 2006; Carmack et al. 2001; Ebraheim et al. 1989; Norris et al. 1999). Penetrating screws can rapidly produce acetabular and femoral chondral scuffing, resulting in accelerated osteoarthritis. Although it would be ideal to detect penetrating screws via radiological means, these techniques have proven inaccurate in some cases (Carmack et al. 2001; Ebraheim et al. 1989; Norris et al. 1999). As an alternative to radiological techniques to direct screw penetration, intraoperative auscultation techniques have also been proposed (Anglen and DiPasquale 1994). An in-depth anatomical knowledge may reduce the incidence of acetabular screw penetration during fixation (Bosse 1991; Ebraheim et al. 1997); however, direct visualization of the acetabular dome may be the most definite method to ensure that no screw penetrates the acetabulum. Arthroscopic visualization enables the direct, real-time detection of chondral lesions due to hardware penetration. This is a valuable tool to control screw positioning during fracture fixation because in many open approaches (i.e., the ilioinguinal approach) direct hip joint observation is not possible (Gotz and Schulz 2013). If a screw does penetrate the acetabulum, direct visualization of the penetrating screw can help to facilitate identification and removal (Fig. 23.5a, b).

23.4 Limitations of Hip Arthroscopy in the Treatment of Acetabular Fracture

With regard to arthroscopic-assisted or all-arthroscopic acetabular fracture fixation, trauma poses multiple challenges to performing hip arthroscopy. Stabile et al. (2014) identified some contraindications for the arthroscopic treatment of bucket-handle labral tears and acetabular fractures. These contraindications include an unstable hip after reduction; patients with serious, medically unstable conditions who do not tolerate surgery; and positioning for hip arthroscopy. Additionally, caution is advised in patients with pelvic trauma, who may be at increased risk of retroperitoneal extravasation and abdominal

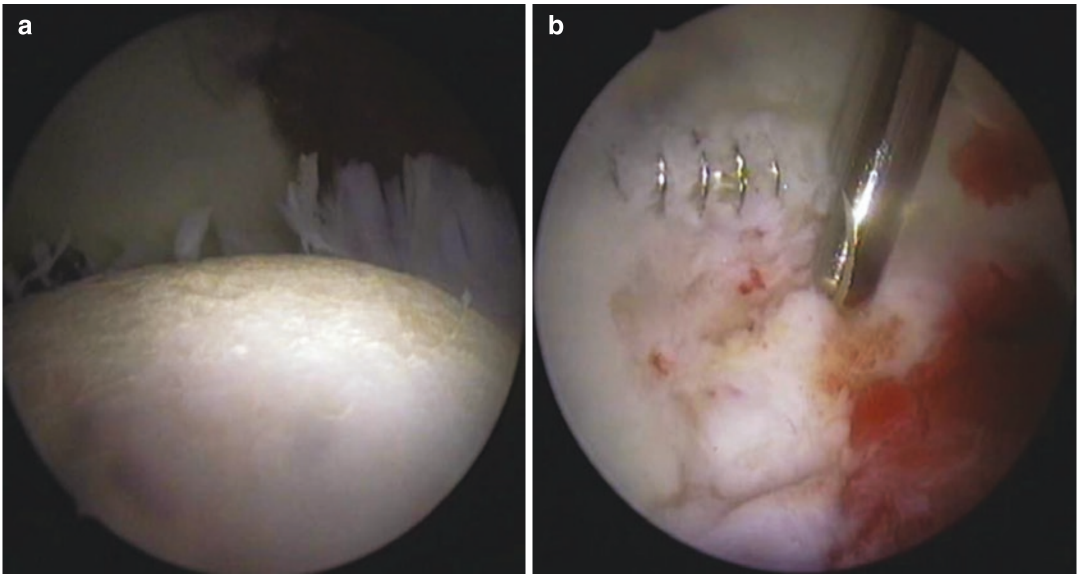

Fig. 23.5 (**a**) Severe chondral scuffing of the femoral head caused by screw penetration into the acetabulum. (**b**) Screw penetrating the acetabulum visualized by arthroscopy to facilitate removal

compartment syndrome. Patients with same-side lower extremity trauma that precludes applying the necessary traction for hip arthroscopy are also contraindicated.

Yamamoto et al. (2003) published a case series including ten patients with heterogeneous hip pathologies sustained from traumatic mechanisms. The authors initially planned for and approached each case arthroscopically. In four of the ten cases, arthroscopic management was deemed impossible, and open procedures were implemented. Arthroscopic management in these four patients was not feasible due to instability of the acetabular bone fragment in one case and severe displacement of bone fragments in the other three cases. The authors offered recommendations for the surgical planning in these complex cases. In the case of large displaced bone fragments, such as Thompson-Epstein (T-E) types III and IV (Thompson and Epstein 1951), fragment reduction may not be possible. In these cases open management may be preferred.

Further improvements in arthroscopic reduction and fixation instrumentation may also increase the capabilities of arthroscopic acetabular fracture fixation. For example, in obese patients, arthroscopic screw fixation may not be feasible due to the need for longer instruments (Kim et al. 2013). It is important to note that currently hip arthroscopy most often serves as an adjunct to other treatment modalities in the setting of acetabular fractures.

23.4.1 Postoperative Care

Only a few studies report on postoperative care after arthroscopic management of acetabular fractures (Gotz and Schulz 2013; Kim et al. 2013; Yamamoto et al. 2003; Yang et al. 2010). Yang et al. (2010) reported mobilization with crutches for transverse acetabular fracture treated with screw fixation. Kim et al. (2013) reported using partial weight-bearing with the aid of two crutches, for 6 weeks, after hip joint fracture dislocation.

Acetabular fractures are very diverse pathologies, ranging from chipped wall to pelvic discontinuity. Postoperative care in the case of acetabular fractures should be determined according to the primary injury, and appropriate treatment should be provided regardless of the surgical technique.

23.4.2 Complications

Patients undergoing hip arthroscopy may experience complications related to traction, portal establishment, overcorrection of the deformity, or iatrogenic injury. When traction is applied for extended periods or with excessive weight, neurapraxia of the femoral or pudendal nerves (Clarke et al. 2003; Sampson 2005), perineal integument injuries, and genitoperineal skin necrosis can occur (Coelho et al. 2008; Hammit et al. 2002). Lateral femoral cutaneous nerve and sciatic nerve injuries are potential risks when establishing the anterior portal and the posterolateral portals, respectively (Robertson and Kelly 2008). Overcorrection of the acetabular rim, especially in dysplastic joints, may provoke subluxation or even frank dislocation (Benali and Katthagen 2009; Matsuda 2009). Iatrogenic damage to the labrum or chondral surfaces should be avoided during surgery. Cases of an induced foreign body creation due to instrument breakage have been reported as well (Clarke et al. 2003; Sampson 2005).

Reports about complications specific to hip arthroscopy for the treatment of acetabular fracture are quite limited (Gotz and Schulz 2013; Kim et al. 2013; Yamamoto et al. 2003; Yang et al. 2010). In the trauma setting, disruption of anatomic compartments and tissue planes may occur by bone fragment penetration or by the high-energy mechanism of injury. Surgeons should be mindful of arthroscopic fluid pressure and vigilant of extravasation to avoid abdominal compartment syndrome, which can lead to circulatory and hemodynamic compromise (Bartlett et al. 1998; Bushnell and Dahners 2009; Mullis and Dahners 2006).

23.5 Conclusion

Arthroscopic management of acetabular fractures is challenging and requires expertise of an experienced surgeon and the support of a qualified team. In selected cases, arthroscopic management of acetabular fractures is advantageous due to its minimally invasive nature. With further developments arthroscopic osteosynthesis may play a larger role in the management of acetabular fractures.

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Arthroscopic Reduction and Internal Fixation of Femoral Head Fractures

24

Dean K. Matsuda

24.1 Introduction

Arthroscopic and endoscopic osteosynthesis is increasingly utilized for certain intra-articular fracture types due to the minimally invasive nature of the procedures and high accuracy (Atesok et al. 2011).

In general, advantages of arthroscopic fracture fixation over open methods are the less invasive and magnified visualization of the intra-articular space and chondral surfaces enabling precise osteochondral fracture reduction while facilitating concomitant treatment of associated intra-articular pathology and accelerated rehabilitation with earlier return to work and sports (Atesok et al. 2011; Matsuda 2013b, 2010). Further advantages include improved cosmesis and potential cost savings of outpatient surgery (Atesok et al. 2011; Matsuda 2013b).

Disadvantages of arthroscopic osteosynthesis include sometimes lengthy, technically demanding procedures with a prolonged learning curve and limited fixation alternatives (Atesok et al. 2011) and the risk of fluid extravasation.

This chapter introduces the indications, utility, key concepts, and surgical techniques for arthroscopic osteosynthesis of select femoral head fractures.

24.2 Femoral Head Fractures

Femoral head fractures are relatively uncommon injuries typically associated with hip dislocations. They tend to be high-energy injuries with historically poor outcomes (e.g., post-traumatic osteoarthrosis and/or osteonecrosis) despite treatment with nonsurgical or open surgical means (Epstein et al. 1985). The more common posterior hip dislocation may cause an infrafoveal fracture (Pipkin 1) in a non-weight-bearing and may tolerate resection of the fragment. Anterior dislocations tend to be associated with more critical weight-bearing suprafoveal fractures of the femoral head. The first reported case of arthroscopy-assisted osteosynthesis was for treatment of a small infrafoveal fracture that was reduced by hip positional manipulation followed by fixation with an absorbable percutaneous pin (Yamamoto et al. 2003). More recently, arthroscopic osteosynthesis has been performed with encouraging short-term outcomes on acute suprafoveal femoral head fractures (e.g., Brumback type 4B associated with anterior hip dislocations) (Matsuda 2009a; Matsuda and Hamani 2012) (Fig. 24.1) and even a femoral head malunion (Matsuda 2013a).

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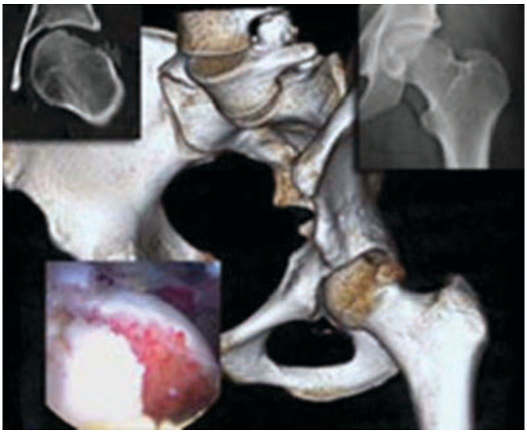

Fig. 24.1 A left femoral head fracture with displaced suprafoveal weight-bearing osteochondral fragment

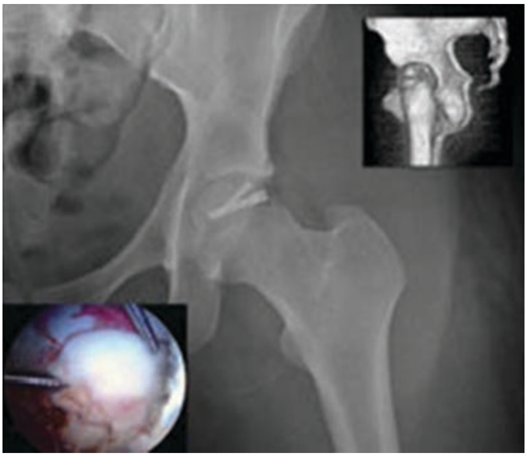

Fig. 24.2 The same fracture during arthroscopic reduction using the “chopstick” maneuver (lower left) and postoperative imaging

Fig. 24.3 Preoperative AP pelvis radiograph showing a double-density shadow of a clamshell suprafoveal femoral head fracture seen after emergent closed reduction of anterior dislocation (Brumback type 4B). Note cam (arrow) and pincer FAI with focal acetabular overcoverage and crossover sign

24.2.1 Preoperative Planning

24.2.1.1 Experience

Arthroscopic osteosynthesis of the femoral head is technically challenging. One should therefore assess his/her personal and surgical team’s experience and ability to perform these procedures in a safe manner.

24.2.1.2 Game Plan/Contingencies

Fixation of critical fragment(s) that contribute to weight-bearing articular congruency (Fig. 24.2) and/or structural integrity is essential, but the surgeon should consider removal of others. If one decides to perform arthroscopic osteosynthesis, a contingency plan is recommended in case the procedure does not proceed as planned. It is better to convert to an open reduction and internal fixation than to perform an inadequate arthroscopic reduction and/or fixation. It is therefore important to keep in mind the general principles of anatomic reduction with secure internal fixation permitting early joint motion. Resection, even arthroscopic, of a critical weight-bearing or structural fracture fragment is the last option if all reasonable attempts at arthroscopic or open osteosynthesis fail.

24.2.1.3 Femoroacetabular Impingement (FAI) Considerations

Acetabular overcoverage from pincer FAI may prevent an acceptable angle of approach for screw fixation of the fracture fragment(s). In such instances, adjunctive arthroscopic acetabuloplasty of the overcovered femoral head may enable successful arthroscopic fixation with headless screws (Matsuda and Hamani 2012) (Figs. 24.3, 24.4, 24.5, and 24.6). One must not cause iatrogenic dysplasia by overzealous rim trimming, and the labrum should be preserved, typically with refixation. Cam FAI, even if previously asymptomatic,

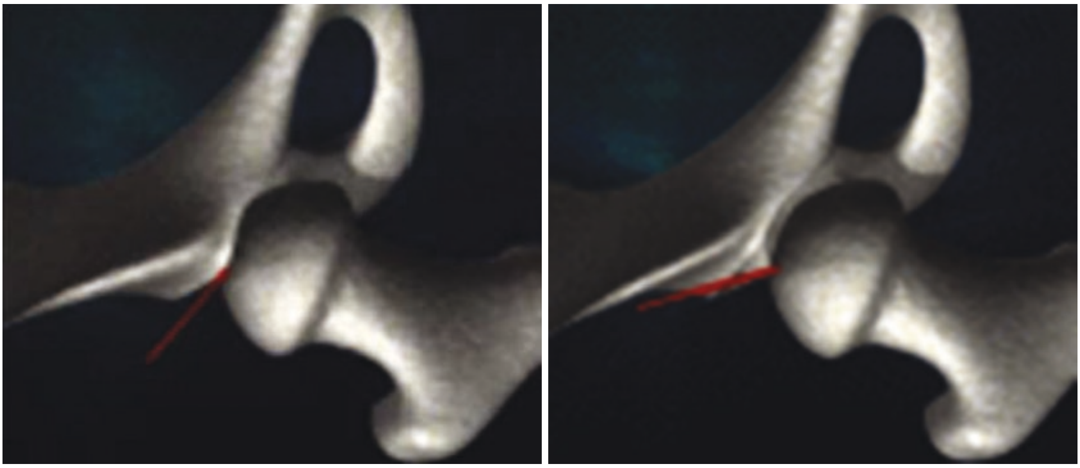

Fig. 24.4 Screw path (red line) before (left) and after (right) arthroscopic acetabuloplasty. A more perpendicular trajectory for screw fixation is achieved

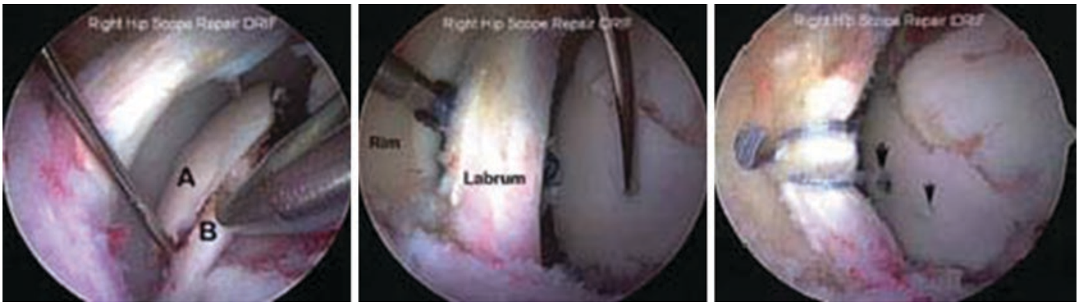

Fig. 24.5 The clamshell fracture with folded osteochondral fragment with superior (**a**) and inferior (**b**) fragments being pried apart with microfracture awl (left). The reduced fracture is being fixated with cannulated headless compression screws (middle). The acetabular rim has been trimmed and the labrum preserved with a screw being inserted between the structures to optimize screw fixation path. Arthroscopic labral refixation is then completed (right). Arrows indicate buried screw heads below the chondral surface

Fig. 24.6 Postoperative healed femoral head fracture. Arrow indicates superolateral acetabuloplasty

may be addressed with arthroscopic femoroplasty without traction as a potentially prophylactic measure. Moreover, if a fracture fragment involves a region of cam morphology, resection of all or part of the fragment may improve the structural offset yielding cam decompression.

24.2.2 Consent

Consent should include arthroscopic and open osteosynthesis plus possible resection of fracture fragment(s). Arthroscopic acetabuloplasty, femoroplasty, and chondrolabral surgery with possible labral debridement, refixation, and reconstruction should be included as appropriate.

24.2.3 Equipment

Ensure that the fracture table and/or portable hip distractor provides sufficient freedom of motion for hip positioning and dynamic testing and does not obstruct fluoroscopic visualization of the operative hip on anterior-posterior and lateral projections. Even if one does not routinely use fluoroscopic guidance for hip arthroscopy, a fluoroscopy image intensifier is strongly recommended and is very helpful, especially when using metallic (radiopaque) screws (see below). A cannulated headless screw system is recommended. These systems vary in their specific instructions so it is necessary to be familiar with the chosen system.

24.2.4 Setup

Although lateral position hip arthroscopy is an option, supine hip arthroscopy will be described. Position the image intensifier between the abducted legs enabling AP, lateral, and dynamic fluoroscopy. The operative hip is positioned in 10 degrees of flexion, 20 degrees of abduction, and 30+ degrees of internal rotation.

Consider using the fluoroscopic templating technique (Matsuda 2009b) especially in patients where one anticipates possible acetabular rim trimming. Moreover, pelvic positioning is standardized by aligning the pelvis to the vertical beam of the fluoroscope in the frontal and sagittal planes prior to surgery.

24.2.5 Traction

A detailed preoperative assessment of sciatic function is important as there is a relatively high incidence of sciatic injury associated with trauma related to hip dislocations.

It is important to remain vigilant of traction time and force (Telleria et al. 2012). Limit the amount of hip distraction to 10 mm of actual space between the acetabular and femoral head chondral surfaces during central compartment arthroscopy. Rather than over-distraction, consider hip adduction along with adjustments in hip rotation to permit acceptable screw trajectory. The use of a traction “time-out” for every hour of applied traction is prudent. Concurrent procedures requiring no traction (e.g., femoroplasty) may be performed during this time.

24.2.6 Portals

The anterolateral portal (ALP) and the modified midanterior portal (mMAP) (Matsuda and Villamor 2014) are used. The latter is typically 3 cm anterior and 4–5 cm distal to the ALP and is made in the aforementioned internal rotated hip position. Typically, a 70-degree arthroscope permits sufficient visualization from the ALP, and the mMAP is the working portal, although interportal exchange is occasionally needed.

A vertical line passing through the anterior superior iliac spine (ASIS) along the operative thigh is a landmark beyond which one should not stray medial to minimize risk of inadvertent neurovascular damage. Percutaneous passage of guide pins and cannulated screws should remain lateral to this landmark whenever possible.

24.2.7 Fluid Pressure

Minimizing arthroscopic fluid pressure minimizes the risk of inadvertent abdominal compartment syndrome. With hypotensive anesthesia, fluid pressure of 50 mmHg is often sufficient for adequate arthroscopic visualization. In some cases, even “dry” arthroscopy may be considered. Intermittent palpation of the draped abdomen, monitoring of hemodynamics and core body temperature, and, if indicated, iliopsoas release at the conclusion of surgery are prudent precautionary measures (Kocher et al. 2012). Intentional removal of intra-articular debris should be performed in hopes of minimizing third-body wear; a suction shaver and high-flow (but low pressure) arthroscopic irrigation may expedite this step and should be repeated at the conclusion of the surgery.

24.2.8 Arthroscopic Reduction

Although closed reduction techniques can be used by manipulating operative hip position for minimally displaced fractures, significantly displaced fractures typically require arthroscopic reduction. A switching stick or probe may enable gross translation of the osteochondral fragment. If fragment derotation is necessary, one may use a toggle stick method; however, this may violate the articular surface. The chopstick technique (Matsuda 2009a) (Fig. 24.2) uses two percutaneous guidewires with two points of chondral contact to aid in fragment derotation for arthroscopic reduction.

24.2.9 Arthroscopic Internal Fixation

Once fracture reduction is achieved, the guide pins used to enable arthroscopic reduction can then be used to provide transient fracture fixation. The percutaneous entry sites for these guidewires should enable an acceptable trajectory for cannulated headless screw fixation. Hip adduction in traction may facilitate arthroscopic screw fixation by exposing some femoral head fractures out from under the obstructive coverage of the acetabulum. Perfectly perpendicular screw fixation is not mandatory for successful fracture union; however, a relatively perpendicular position is desirable as it permits optimal engagement of subchondral bone while seating the headless screw below the chondral surface. Current headless compression screw design compresses the fracture site with antegrade advancement. Typically, two or three screws (Acutrak mini, Acumed, Hillsboro, Oregon) are required although this will vary with the size and thickness of the osteochondral fragment. Avoid overzealous antegrade screw advancement as this may lose subchondral purchase and compromise compression if one then decides to partially back the screw out in a retrograde manner.

Although radiolucent bioabsorbable implants may be used, an advantage of metallic headless screws is that their position may be monitored to detect even subtle joint encroachment via intraoperative fluoroscopy and postoperative radiographs (Matsuda 2009a). If detected, one may perform arthroscopic screw removal or antegrade screw advancement. A relative disadvantage of metallic implants is unwanted scatter from computed tomographic and magnetic resonance imaging, although some scanners have metal subtraction technology.

24.2.10 Dynamic Arthroscopic and Fluoroscopic Testing

Dynamic arthroscopic and fluoroscopic examinations confirm safe positioning of headless screws and also confirm the absence or eradication of coexistent FAI. Static biplane fluoroscopy may not detect a proud screw violating the joint. Rotating the fluoroscopy beam around the femoral head and moving the hip are both acceptable methods, although the latter may permit more range of motion including internal and external rotation and may be quicker with less radiation exposure.

24.2.11 Postoperative Considerations

Early range of hip motion while protecting against excessive weight-bearing is desired. Typically, 6–8 weeks of protected weight-bearing of the operated hip with two crutches or a walker is sufficient. Exercise bicycling is permitted after 1 week, and swimming (freestyle stroke) and jogging in a pool begin when portals are healed. Return to impact activity is individualized to the patient and his/her fracture, but even in the best case scenario, running is not initiated until 3 months postsurgery. Key pearls and pitfalls of arthroscopic femoral head osteosynthesis are provided in Table 24.1.

Table 24.1 Pearls for arthroscopic reduction and internal fixation of femoral head fractures

Perform accurate preoperative fracture assessment
Perform accurate preoperative self-assessment of surgical team experience and arthroscopic skills
Be willing to perform possible open reduction and internal fixation (rather than arthroscopic fragment removal) if the arthroscopic method fails
Consider fluoroscopic templating technique to standardize pelvic position under hip distraction
Hip adduction may improve the path for screw fixation
If pincer FAI exists, acetabuloplasty of the overcoverage may improve the path of screw fixation
Do not cause iatrogenic dysplasia
Pay careful attention to safe portal placement (may require several accessory portals), capsulotomies, intra-articular fluid pressure, and distraction amount and time
Mobilize, translate, and reduce fracture fragment(s); consider the use of "chopstick" technique where indicated
Consider arthroscopic fixation using radiopaque screw(s) or pin(s) visible under intermittent fluoroscopic guidance
Consider removal of osteochondral bone not essential to weight-bearing or structural integrity of fracture construct
Confirm accurate reduction and stable fixation by arthroscopic and fluoroscopic dynamic testing
Allow early hip mobilization and protected weight-bearing commensurate with assessed fracture fixation
Perform interval postoperative radiographic assessment with special attention to joint space narrowing, hardware migration, and hip joint violation

24.3 Femoral Head Malunions

Femoral head malunions (Fig. 24.7) present a degree of technical complexity beyond acute femoral head fracture fixation. After removal of any surgical hardware, one must locate the malunion site via arthroscopic and fluoroscopic visualization. Although percutaneous screws used in femoral neck fracture fixation are typically readily removed, smaller screws of the femoral head may be buried. As long as the malunion site is identifiable, the malunion may be mobilized using straight and/or angled osteotomes (Fig. 24.8) via percutaneous placement in safe areas lateral to the vertical line passing through the ASIS. Then, arthroscopic reduction may be performed using the aforementioned techniques. Moreover, any retained bent screw may actually aid reduction; hitting it with a mallet and small osteotome, the screw may straighten, indicating improved reduction while distributing impact forces across a larger surface area (Matsuda 2013a).

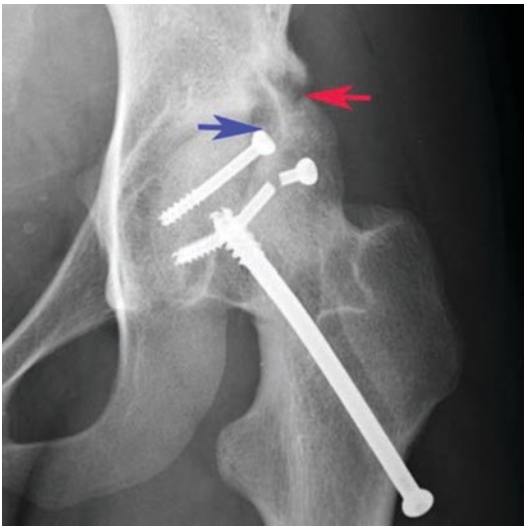

Fig. 24.7 Femoral head malunion after initial ORIF failed with premature ambulation. Note that the lateral column of femoral head fracture (red arrow) is causing laterocephalic acetabular impingement against the superolateral rim. The inferior malunion is >1 cm displaced (blue arrow). The long screw was removed prior to takedown of the malunion

Once the femoral head malunion is mobilized and reduced, arthroscopic bone grafting may be performed by passing graft material via a cannula. Osteoinductive bone graft can be "muzzle-loaded" into an arthroscopic cannula. The "loaded" cannula can then be positioned through the mMAP and positioned so that the graft substance can be inserted into the malunion site (Fig. 24.8) in a controlled manner using a matching blunt stylet as a plunger under transient "dry" arthroscopic visualization (Jamali et al. 2010; Matsuda 2013a). Upon completion, arthroscopic fixation of the previously malunited fracture may be performed using aforementioned arthroscopic headless screw fixation techniques or, if the femoral head fragment is sufficiently large, outside-

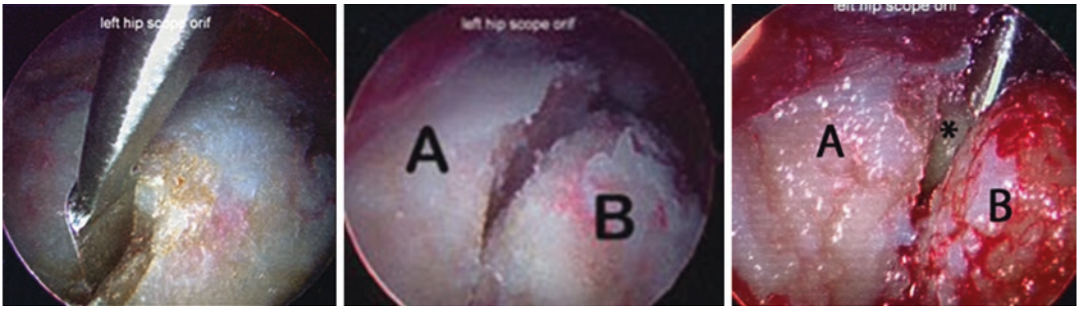

Fig. 24.8 Supine arthroscopic images during arthroscopic takedown using angled osteotome (left), after arthroscopic reduction (middle), and during arthroscopic insertion of bone graft putty via cannula under dry arthroscopic visualization (right) prior to compression of fracture site with percutaneous lag screws. *A* = medial femoral head fragment, *B* = intact lateral column, * = bone graft

Fig. 24.9 Postoperative radiograph with reduced and fixated malunion. Note straightened inferior femoral head screw and eradication of laterocephalic acetabular impingement

in percutaneous fixation using 7 mm cannulated screws under fluoroscopic guidance (Fig. 24.9).

24.4 Conclusion

Arthroscopic reduction and internal fixation of select femoral head fractures have been performed with encouraging outcomes. It is conceivable that hip arthroscopy will play a larger role in the minimally invasive future treatment of selected acute and even malunited femoral head fractures.

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25

The Role of Hip Arthroscopy in Posttraumatic Hip Dislocation

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Traumatic dislocations of the native hip are rare high-energy injuries, usually seen in young male adults (Clegg et al. 2010; Dreinhöfer et al. 1994; Ilizaliturri Jr et al. 2011; Lima et al. 2014; Sahin et al. 2003; Upadhyay and Moulton 1981) and in the vast majority (85–90%) posterior in direction (DeLee 1996). Severe complications like posttraumatic arthritis or avascular necrosis of the femoral head are common, and factors such as the direction of dislocation, time lapsed from injury to reduction, the overall severity of trauma, and even the patient's occupation seem to affect prognosis (Dreinhöfer et al. 1994; Kellam and Ostrum 2016; Upadhyay et al. 1983). Posttraumatic hip arthritis develops in 24% of simple dislocations and in up to 74% in dislocations associated with acetabular or femoral head fractures (Foulk and Mullis 2010; Upadhyay and Moulton 1981; Upadhyay et al. 1983).

Hip arthroscopy is a newly established surgical technique and as such is still evolving. Arthroscopy of the hip after dislocation has been reported in only few retrospective studies and case reports but needs to be considered as a valuable minimal invasive technique in the diagnosis and treatment of posttraumatic intra-articular pathology (Kellam and Ostrum 2016).

25.1 Imaging Limitations and the Value of Diagnostic Hip Arthroscopy

Hip injuries are associated with intra-articular pathology that may not be apparent on radiographs, CT scans, or even in magnetic resonance imaging/arthrography (MRI/MRA) (Khanna et al. 2014). Hip arthroscopy however will reveal intra-articular pathologies such as loose bodies, osteochondral lesions, and tears of the ligamentum teres and labrum (Byrd and Jones 2004; Ilizaliturri Jr et al. 2011; Stabile et al. 2014) that if left untreated may lead to early joint degeneration and osteoarthritis.

Several clinical studies have confirmed the ability of hip arthroscopy to locate and treat previously unidentified pathology. Mullis and colleagues in their retrospective study found loose bodies during arthroscopy in 33 of 36 patients (92%) (Mullis and Dahners 2006). Similarly, in a case series by Yamamoto et al., 7 of 11 hips had findings of loose chondral or osteochondral fragments during arthroscopy that were not detected in preoperative imaging (Yamamoto et al. 2003). Khanna and colleagues compared the prevalence of intra-articular pathology seen in arthroscopy versus conventional imaging in 29 dislocated hips (Khanna et al. 2014). In this study, plain radiographs and CT scans yielded low sensitivity for the identification of loose bodies and osteochondral step deformities. They also

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reported that MRI and MRA were very accurate in the identification of labral tears but less so in identifying osteochondral lesions compared with arthroscopy.

The superior diagnostic ability of arthroscopy constitutes an important tool for diagnosis of intra-articular pathologic lesions following trauma not evident preoperatively. This is an area where hip arthroscopy can make an impact on outcomes.

25.2 Indications for Hip Arthroscopy After Dislocation

Hip arthroscopy certainly cannot be advocated for every patient who has a traumatic hip dislocation. However, hip arthroscopy is a valuable option instead of open arthrotomy for the treatment of the irreducible hip due to loose bodies and labral incarceration and for mechanical hip symptoms including catching and locking (Kellam and Ostrum 2016; Stabile et al. 2014). More than 65 years ago, Thompson and Epstein discussed the importance of removing "loose fragments" to restore articular congruity and to prevent the development of traumatic arthritis in the hip (Thompson and Epstein 1951). The most common intra-articular lesions seen during an arthroscopic examination after a hip dislocation are osteochondral lesions, loose bodies, and labrum and ligamentum teres tears (Table 25.1).

25.2.1 Loose Bodies

Arthroscopically diagnosed loose bodies were reported in almost 80% of the cases including patients in whom loose bodies were not identified on CT or other imaging modalities (Table 25.1). Thus, identification and removal of loose bodies remain the primary indication for hip arthroscopy.

Table 25.1 Common intra-articular pathologies seen during an arthroscopic examination after a hip dislocation

	Year published	No. of patients/ hips	Presence of FAI/ treatment	Loose bodies	Labral tear	Osteochondral lesions acetabulum and/or femoral head	Ligamentum teres rupture complete or partial
Keene and Villar	1994	1	No data	1	No data	No data	No data
Byrd	1996	3	No data	3	No data	No data	No data
Yamamoto et al.	2003	10/11	No data	7	No data	11	No data
Svoboda et al.	2003	1	No data	1	No data	1	No data
Byrd and Jones	2004	6	No data	3	2	3	6
Mulis and Dahners	2006	36/39	No data	33	No data	No data	No data
Philippon et al.	2009	14	9	11	14	14	11
Cross and Shindle	2010	1	1	1	1	1	1
Ilizaliturri et al.	2011	17	No data	14	16	17	17
Krych et al.	2012	11	8	8	11	9	9
Stabile et al.	2014	1	1	1	1	1	No data
Hwang et al.	2015	13	2	5	10	No data	9
Total		**114**	**21**	**88**	**55**	**57**	**53**

25.2.2 Labral Tears

With the evolution of surgical techniques and the appreciation of the importance of the labrum, in recent clinical studies, labral tears have been documented in 53 out of 55 patients (Cross and Shindle 2010; Hwang et al. 2015; Ilizaliturri Jr et al. 2011; Krych et al. 2012; Philippon et al. 2009; Stabile et al. 2014). Labral tears apart for their structural importance may contribute to posttraumatic pain commonly seen in these patients. Ilizaliturri in his paper that included 17 patients, using the geographical zone method (Ilizaliturri Jr et al. 2008), showed that 14 patients had anterior labral tears (9 in zone 2 and 5 in zone 1), 6 had posterior labral tears (5 in zone 4 and 1 detachment in zones 4 and 5), and in 3 patients, tears were present in both the anterior and the posterior labrum. These results agree with a retrospective study by Shindle and colleagues which showed that 13 out of 14 patients following hip subluxation or dislocation had MRI or arthroscopic evidence of an anterior labral tear including 3 with associated posterior tear (Shindle et al. 2008). Kyrch and colleagues in a series of 11 athletes who underwent arthroscopy for posterior hip subluxation-dislocation found 9 anterior labral tears, while all of them had posterior labral injury (Krych et al. 2012).

Labral tears following high-energy trauma are usually complex (Figs. 25.1 and 25.2). A complex tear disrupts the longitudinal fibers of the labrum, and as a result, the ability to provide a suction seal with the femoral head is lost (Newman et al. 2015). Where adequate tissue is available, labral tears should be repaired (Ilizaliturri Jr et al. 2011; Philippon et al. 2009; Stabile et al. 2014). Debridement is generally used for degenerative or very small tears.

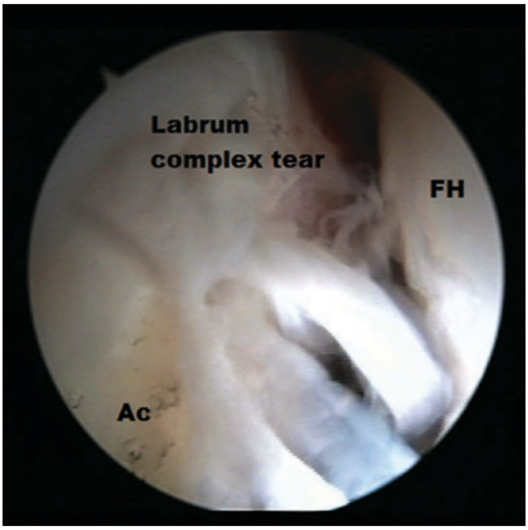

Fig. 25.1 Arthroscopic view of the right hip through anterolateral viewing portal showing an anterior complex labral tear (zone 1) (*FH* femoral head, *Ac* acetabulum, *LT* ligamentum teres, *CF* cotyloid fossa)

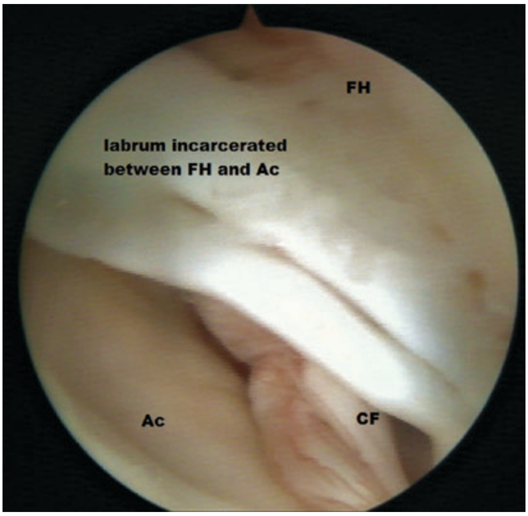

Fig. 25.2 Arthroscopic view of the left hip through anterolateral viewing portal showing a detached labrum incarcerated in the joint (zone 2) (*FH* femoral head, *Ac* acetabulum, *LT* ligamentum teres, *CF* cotyloid fossa)

25.2.3 Osteochondral Lesions

Cartilage injuries are commonly seen as kissing lesions (both acetabulum and femoral head) located mainly in zone 3 and at a lesser degree in zones 2, 4, and 5 on acetabulum side and zone 3 on the femoral head (Fig. 25.3). Treatment options include debridement, chondroplasty, microfracture, mosaicplasty, chondrocyte implantation, and even partial resurfacing (Newman et al. 2015). In acute cartilage damage due to trauma, factors such as the size of the lesion, patient com-

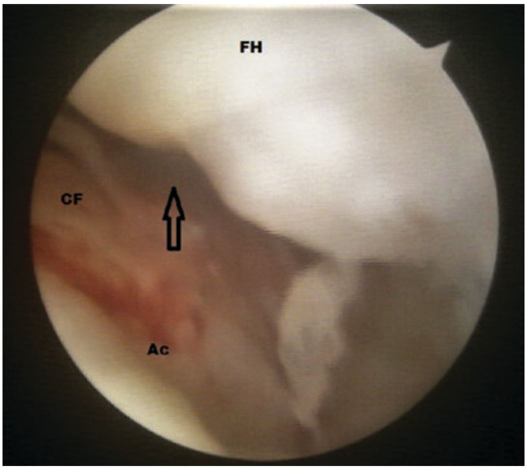

Fig. 25.3 Arthroscopic view of the left hip through anterolateral viewing portal showing (arrow) a femoral head osteochondral/chondral injury (zone 3) (*FH* femoral head, *Ac* acetabulum, *LT* ligamentum teres, *CF* cotyloid fossa)

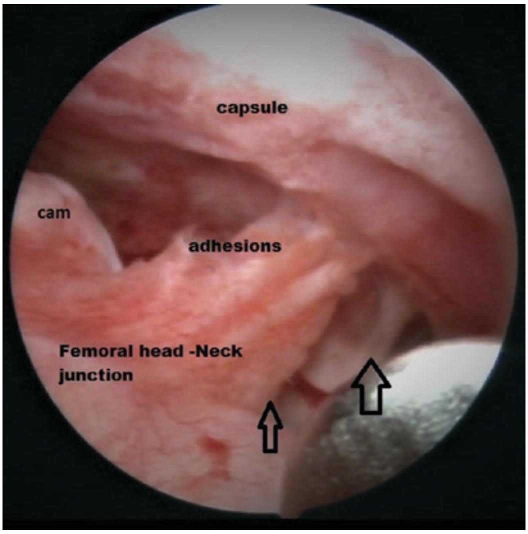

Fig. 25.4 A view of the peripheral compartment demonstrates chronic cam lesion of the femoral head-neck junction with a number (arrows) of posttraumatic adhesions

pliance, and quality of underlying bone can affect the treatment choices. The current treatment of choice for chondral injury is microfractures. Recently, Nam and colleagues reported two cases of traumatic chondral defects after hip dislocation that were treated with osteochondral autografts (OATS) using a surgical dislocation of the hip (Nam et al. 2010).

25.2.4 The Femoroacetabular Impingement (FAI) Implication

Philippon proposed that FAI predisposes athletes to posterior hip instability (Philippon et al. 2009). Evidence of preexisting FAI was seen in 9 out of the 14 athletes. Four patients had isolated cam lesions, one had an isolated pincer lesion, and four had evidence of mixed-type pathology. Following his paper several other authors have reported on this coexistence (Cross and Shindle 2010; Hwang et al. 2015; Krych et al. 2012; Stabile et al. 2014). FAI is a clinical syndrome associated with structural abnormalities of the hip causing abnormal contact stresses in the hip that can lead to pain, dysfunction, cartilage damage, and chondrolabral dysfunction (Ganz et al. 2003). This suggests that some of the patients with hip dislocation and FAI may had a preexisting chondral or labral lesion (Fig. 25.4). It may also imply that microfractures or labral repair needs to be protected by addressing any bony impingement (Newman et al. 2015).

25.2.5 Ligamentum Teres Rupture

The unique anatomy of the ligamentum teres (LT) predisposes it to rupture during a hip dislocation (Bardakos and Villar 2009; De Sa et al. 2014). It is actually a very common finding during hip arthroscopy post trauma (Table 25.1 and Fig. 25.5). Although it is believed to serve as a secondary stabilizer, much remains unknown on its contribution to proprioception and joint lubrication (De Sa et al. 2014). LT lesions may also be associated with pain and mechanical symptoms such as locking.

Although the ruptured LT may heal (Schaumkel and Villar 2009) after a traumatic dislocation of the hip, the routine treatment is debridement (Niroopan et al. 2016). Byrd and Jones reported on 23 traumatic LT tears that presented with hip pain that underwent arthroscopic debridement

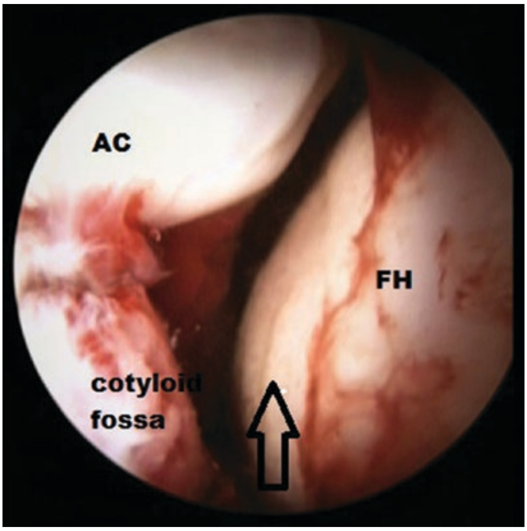

Fig. 25.5 Arthroscopic view of the right hip through anterolateral viewing portal showing synovitis of the hip and the absence of ligamentum teres (arrow) (*FH* femoral head, *Ac* acetabulum, *LT* ligamentum teres, *CF* cotyloid fossa)

and reported significant improvement postoperatively (Byrd and Jones 2004). Similar excellent results in a group of 29 patients with symptomatic isolated LT rupture were reported by other authors (Haviv and O'Donnell 2011).

25.3 Interpretation of the Available Literature

The cohort of patients reported in the literature that underwent hip arthroscopy after a hip dislocation is not homogeneous in age, time to reduction, type or force of injury, time to arthroscopy, or even surgical ability and pathology. This is mainly due to the fact that the publications range over the last 20 years during which hip arthroscopy evolved dramatically (Hwang et al. 2016; Keene and Villar 1994). Despite this heterogeneity most authors report excellent clinical post-op results in their series.

Byrd, with a mean follow-up of 2 years and 6 months, reported that the average preoperative Modified Harris Hip Score (MHHS) score of 47 improved postoperatively to 90 with almost all of the patients (96%) achieving a 20-point improvement (Byrd and Jones 2004). Yamamoto in his series of 11 hips with a mean postoperative follow-up of 9 years and 6 months in the latest follow-up documented 1 patient with osteoarthritis and 1 who developed osteonecrosis (ON) of the femoral head (Yamamoto et al. 2003). Philippon, looking at 14 professional athletes, reported excellent short-term outcome in all cases with return to competition. However, this series long-term follow-up is lacking (Philippon et al. 2009). Owens and Busconi described a consecutive cohort of patients undergoing hip arthroscopy for loose bodies after dislocation with a successful outcome in all patients (Owens and Busconi 2006). Ilizaliturri et al. (2011) with a mean follow-up of 3 years and 9 months reported significant improvement in WOMAC scores (46 to 87). Only 2 patients out of 17 required total hip replacement, 1 for osteoarthritis and 1 for ON (Ilizaliturri Jr et al. 2011). In a recent report of 13 patients by Hwang J-T et al. (2015) with a mean follow-up of 5 years, VAS and MHHS improved significantly from 6.3 and 53.4 to 3.0 and 88.3, respectively. Hip range of motion did not improve, but no hip progressed to osteoarthritis or ON (Hwang et al. 2015). In a study that examined 22 athletes with low-energy posterior hip instability, good overall function was reported at 4-year follow-up, with a mean MHHS of 94 (range, 90–96), a mean HOS ADL of 99 (range, 98–99), and a mean HOS Sport of 87 (range, 81–100) (Krych et al. 2012). However, this was a mixed group of patients with only half treated arthroscopically. From those, nine returned to sport at their previous level.

25.4 Complications

Despite the limited invasiveness of hip arthroscopy, there are some risks associated when treating hip trauma: irretrievable/retained loose bodies (4.1%), AVN (1.4%), and transient lateral femoral cutaneous nerve palsy (0.7%). The most significant complication reported was one case of fatal pulmonary embolism and one case of abdominal compartment syndrome (Bardakos and Papavasiliou 2012; Bartlett et al. 1998; Niroopan et al. 2016; Papavasiliou and Bardakos 2012).

25.5 Cautionary Note

Following trauma, the integrity of the anatomic compartments is often compromised because of disrupted tissue planes or acute fracture sites. As such, vigilance regarding arthroscopic fluid extravasation is of the outmost importance in the avoidance of compartment syndrome and subsequent circulatory and hemodynamic compromise. To minimize these potential complications, if hip arthroscopy is decided, the earliest it can be performed is 3–6 weeks post trauma to allow for the capsule to heal in order to avoid the risk of retroperitoneal and intraperitoneal extravasation of irrigation fluid to the abdomen and surrounding tissues (Newman et al. 2015).

25.6 Conclusion

Hip arthroscopy appears effective and safe in the setting of trauma. The data presented should be interpreted with caution because of the low-quality evidence of the included studies (case reports and case series). We recommend for increased multicenter collaboration in imaging and surgical data collection to advance the quality of existing literature.

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Posterior Acetabular Rim Fractures

26

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26.1 Introduction

In recent years, arthroscopic-assisted intra-articular fracture fixation has become more widespread due to the minimally invasive nature of the procedure. Although it is technically demanding, it enables direct visualization of the intra-articular space, thereby enabling diagnosis and even simultaneous repair of associated soft tissue and osteochondral pathologies accompanying the intra-articular fracture (Atesok et al. 2011). However, arthroscopic-assisted intra-articular fracture fixation represents an intersection point for sports medicine arthroscopists who usually do not encounter such cases and orthopedic trauma surgeons, who are not as familiar with arthroscopic procedures (Atesok et al. 2011).

Unlike other fracture regions, arthroscopic management of the hip joint is reasonable in terms of minimal invasiveness (Kim et al. 2014; McCarthy and Lee 2006). However, only a limited number of patients with hip trauma are treated using hip arthroscopy due to limited indications and safe positioning for trauma patients.

Hip trauma can be divided into two groups: patients with dislocations and patients without dislocations. Hip dislocations are then divided into simple dislocations without fracture and complex dislocations with fracture. The common practice for a dislocated hip is prompt reduction, to avoid iatrogenic intra-articular damage. Femoral head avascular necrosis is another problem, which develops in 10–35% of hip dislocations, and is much dependent on the time until reduction and injury severity (Foulk and Mullis 2010). If the time to reduction is more than 6 h, femoral head avascular necrosis may occur in up to 60% of patients (Hougaard and Thomsen 1987). Fluoroscopy-assisted intracapsular needle aspiration to decrease intra-articular pressure is recommended to reduce the likelihood of avascular necrosis (Newman et al. 2015). After reduction, pelvis CT including sagittal, coronal, and axial reconstructions is routinely recommended to confirm reduction by comparison with the contralateral hip. If the reduction is complete and there are no intra-articular loose bodies,

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nonsurgical management can be an option for simple, non-displaced, or minimally displaced fractures. However, posttraumatic osteoarthritis subsequent to hip dislocation has been reported in 24% after simple dislocations and 88% after complex dislocations (Upadhyay and Moulton 1981). These reports are contradictory to the belief that simple dislocations usually have a good prognosis. Residual loose bodies are considered responsible for the development of the osteoarthritic changes due to increased chondrolytic enzymes in the hip joint and damage to the articular surface through a wear mechanism (Epstein et al. 1985; Evans et al. 1984). Routine pelvis CT after reduction is useful to confirm reduction, although the effectiveness to detect loose bodies is more questionable (Khanna et al. 2014; Yamamoto et al. 2003).

The use of arthroscopy in hip trauma cases was first presented by Goldman et al. (1987) with the extraction of a bullet from the posterosuperomedial femoral articular surface. Keene and Villar (1994) thereafter reported the first arthroscopic removal of loose bodies after traumatic hip dislocation. Subsequently, Byrd (1996), Svoboda et al. (2003), Yamamoto et al. (2003), and Mullis and Dahners (2006) all reported arthroscopic removal of loose bodies after traumatic dislocation. Philippon et al. (2009), Ilizaliturri et al. (2011), and Hwang et al. (2015) emphasized the efficacy of arthroscopy in the diagnosis and treatment of a variety of intra-articular hip pathologies such as labral tears and chondral damage in addition to intra-articular loose bodies. In addition, several authors have reported about arthroscopic reduction and fixation of acetabular and/or femoral head fractures (Kim et al. 2014; Matsuda 2009; Matsuda 2012; Park et al. 2013, 2016; Yamamoto et al. 2003; Yang et al. 2010).

26.2 Case

A 51-year-old male who was transferred had a car accident. The patient sustained posterior dislocation of the right hip with no neurological deficit and no severe injury to any other body region. Reduction was applied promptly with closed manipulation in the emergency department. Plain radiographs and pelvis CT were taken to evaluate the reduction in comparison with the contralateral hip. Postreduction CT revealed loose bodies and a posterior acetabular rim fracture (Fig. 26.1). Hip arthroscopy was then planned for joint debridement and posterior acetabulum rim fixation. Five days after the trauma, surgery was performed under general anesthesia in a supine position using traction of the affected limb. First, posterior subluxation of the joint was identified at 90° of flexion with a posteriorly directed force. A standard anterolateral viewing portal was used with additional posterior paratrochanteric and anterior portals. After hematoma evacuation, the hip joint was visualized using a 70°-angled arthroscope. While viewing through the anterior portal, a fracture fragment with attached labrum was detected in the 10–11 o’clock position. The fracture bed was debrided, and the fragment was mobilized using a rasp and shaver through the anterolateral portal. Two sutures were passed around the fracture fragment, piercing the labrum in a mattress configuration, and a knotless anchor (DePuy, USA) was implanted into the fragment under arthroscopic vision enabling effective reduction (Fig. 26.2). A torn ligamentum teres was then debrided with a shaver. Fragment reduction and hip joint stability were then evaluated. On the 3-month postoperative follow-up CT, partial union of the fragment with the acetabulum was observed (Fig. 26.3a, b). The patient was asymptomatic. On the 18-month postoperative follow-up CT, union of the fragment was observed with minimal joint line narrowing and sclerosis (Fig. 26.3c). The patient was also asymptomatic.

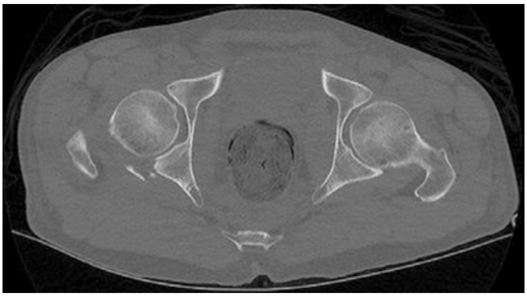

Fig. 26.1 Preoperative CT scan

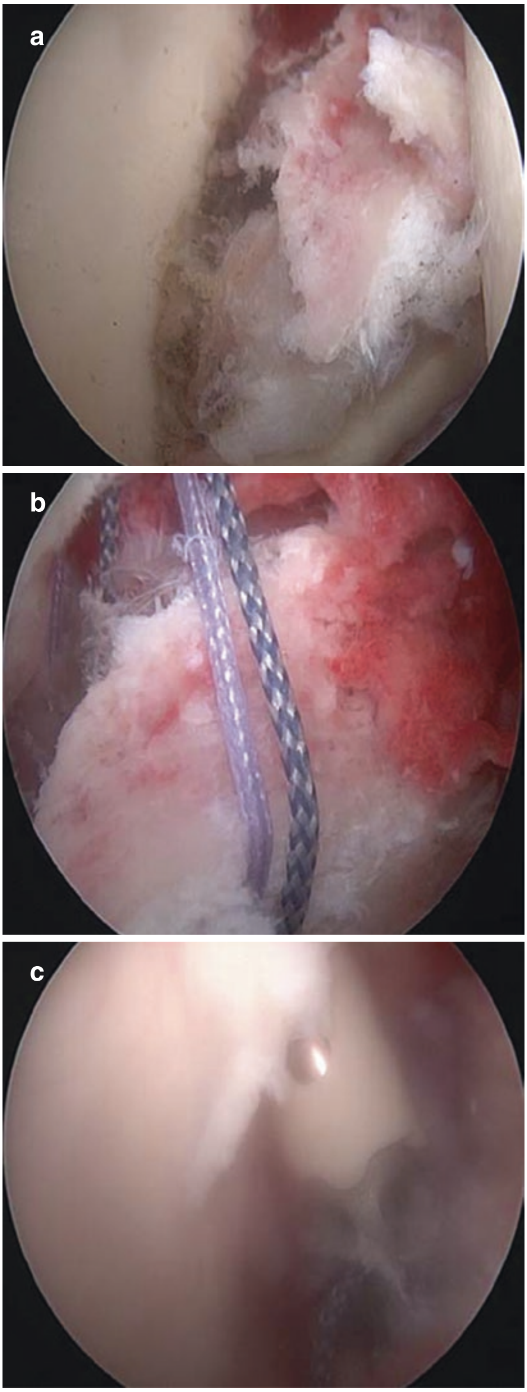

Fig. 26.2 (**a**) Posterior acetabular rim fracture. (**b**) After suture passage. (**c**) Knotless Versalok anchor (DePuy, USA) implantation

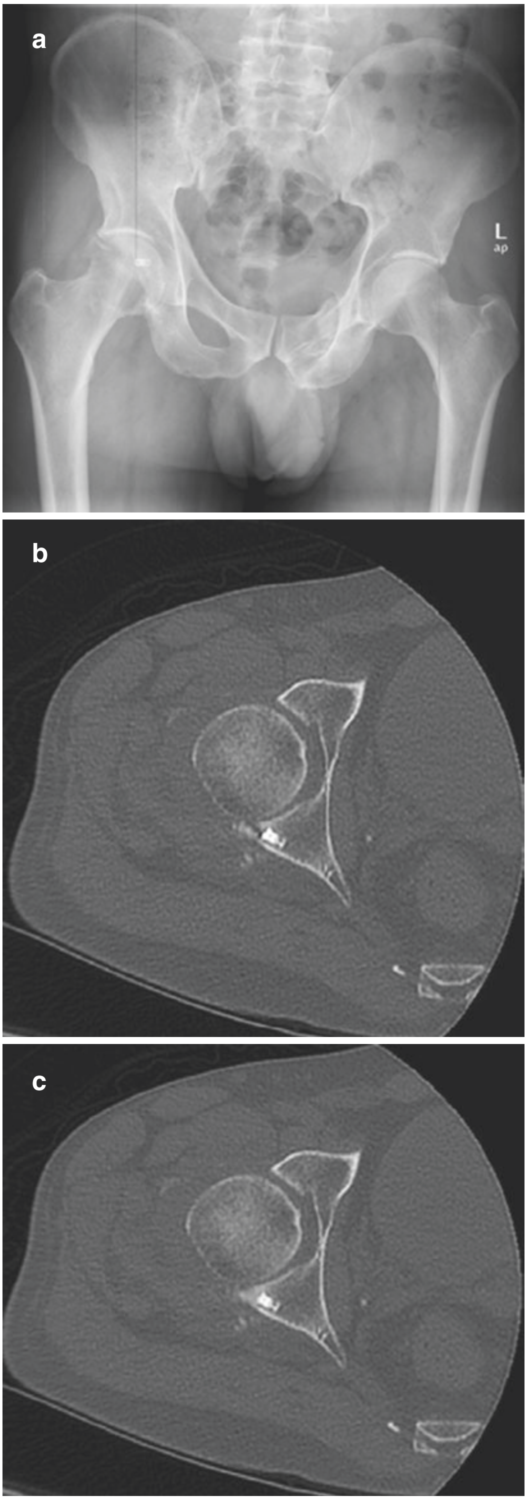

Fig. 26.3 (**a**–**c**) Postoperative follow-up; X-ray and CT scan

26.3 Discussion

As an emerging field, limited literature supports the efficacy of arthroscopically assisted fracture surgery (Kim et al. 2014; Park et al. 2016; Yamamoto et al. 2003; Yang et al. 2010). Yamamoto et al. (2003) reported a series of 11 patients with hip trauma. They performed femoral head fracture fixation with an absorbable pin in one joint, extraction of a femoral head fracture in one joint, and percutaneous fixation of an acetabulum fracture in the weight-bearing zone in one joint. In four patients, which were judged as impossible to fix arthroscopically due to severe displacement and instability of the fragments, open reduction and fixation were performed after arthroscopic debridement of small osteochondral fragments. They also reported that 8 of 11 patients had loose bodies, none of which were diagnosed with preoperative imaging. They emphasized the importance of arthroscopically examining joints with Thompson-Epstein type 1 and 2 fractures, which surgeons may hesitate to open for possible fragment removal. On the other hand, they described arthroscopic fixation of Thompson-Epstein type 3 and 4 fractures as impossible (Yamamoto et al. 2003). Yang et al. (2010) reported two cases of acetabulum fracture fixation with percutaneous screws in which arthroscopy was used as an assisting instrument for anatomic fracture reduction and avoidance of acetabular penetration during screw insertion. They emphasized the additional benefits of this technique for joint lavage, for reduced radiation exposure, and for safe screw fixation, in addition to lower costs than fluoroscopy-based navigation systems (Yang et al. 2010). Kim et al. (2014) reported two patients who were treated arthroscopically with loose body removal and debridement. One of these patients had an acetabulum posterior wall fracture that was fixed using 4.0-mm-diameter cannulated screws and an anterior column fracture that was fixed using cortical screws. They emphasized that difficulties associated with the techniques used for fracture fixation warranted a need for high specialization in hip arthroscopy, further improvements in surgical instruments such as a longer guide and drills (especially for obese patients), and indications being limited to only minimally or moderately displaced acetabular fractures (Kim et al. 2014). Park et al. (2016) similarly reported two cases with posterior acetabular wall fracture, treated by arthroscopic reduction and transportal 4.0-mm-diameter cannulated screw fixation. They used a curved guide through arthroscopic portals instead of a straight guide wire, in order not to penetrate the articular surface. Similar to Yamamoto et al. (2003), they emphasized that this technique is not suitable for severely comminuted fractures as they cannot be adequately compressed using compression screws.

The case presented here is a posterior acetabular rim fracture, and the treatment was arthroscopic fixation of the rim fracture and labrum repair with a knotless anchor (DePuy, USA). In contrast to previous case reports, fixation was made with an anchor because the fractured rim was relatively small. Bioabsorbable internal fixation screws, absorbable or radiolucent anchors, and sutures are other possible fixation alternatives that can be used in arthroscopic-assisted fracture fixation (Atesok and Doral 2011). In this case, intra-articular loose bodies could be arthroscopically debrided (Kim et al. 2014; Park et al. 2016; Yamamoto et al. 2003; Yang et al. 2010). The opportunity is also useful to evaluate other intra-articular structures such as the ligamentum teres, femoral head and acetabular chondral surface, and anterior labrum in addition to the posterior labrum and posterior acetabular rim, with the advantage of avoiding invasive arthrotomy. If open arthrotomy with a posterior approach had been planned for this posteriorly dislocated hip, it is difficult to visualize anterior intra-articular structures such as the anterior labrum and even anterior extra-articular structures.

The ideal indications for hip arthroscopy after traumatic hip dislocation are accepted as nonconcentric reduction or intra-articular loose bodies (Foulk and Mullis 2010; Philippon et al. 2009; Svoboda et al. 2003; Yamamoto et al. 2003). However, in cases with simple dislocations and dislocations with fracture, if the reduction is concentric with no detected intra-articular loose bodies and even without acetabular wall fragment displacement, the surgeon may be reluctant to operate especially with an open approach due to its invasiveness and related morbidity. The surgeon must keep in mind the problem of detection of intra-articular osteochondral loose bodies with pelvis CT, even with MRI/MRA. Katayama et al. (1987) reported that 16 of 20 patients in which osteochondral fragments were detected during surgery could have been detected with preoperative plain radiographs and CT scans. They emphasized that fragments <5 mm in size are difficult to detect with CT scans. Conversely, Baird et al. (1982) reported that fragments >2 mm could be detected using CT, while fragments >4 mm were detectable with plain radiographs. The chondral nature of loose bodies has also been proposed as a possible reason for lack of detection on CT scans (Khanna et al. 2014). Yamamoto et al. (2003) reported arthroscopy in 11 patients with traumatic hip dislocation in which 8 had loose bodies, but none were diagnosed on preoperative imaging. Mullis and Dahners (2006) reported on 39 patients with traumatic hip injuries who subsequently underwent hip arthroscopy. Loose bodies were found in the hips of 33 of 36 patients (92%) and 7 of 9 patients (78%) in which standard radiographic studies (AP pelvis radiographs and CT scans) found no loose bodies and a concentric reduction. MRI/MRA has been reported as a useful tool to detect labral pathology, however, it is not as effective in the detection of small osteochondral lesions (Khanna et al. 2014).

Hip pain following hip dislocation or acetabular fracture is another issue associated with anatomical reduction, intra-articular loose bodies, hip instability, and concomitant injuries (Hwang et al. 2015). Labral tear, ligamentum teres injury, articular cartilage injury, and loose bodies are the most common intra-articular sources of hip pain and can be a potential sign of early osteoarthritic changes (Byrd 1996; Philippon et al. 2009). Ilizaliturri et al. (2011) reviewed 17 patients that had undergone hip arthroscopy after a mean of 3 months, due to mechanical hip symptoms after a traumatic posterior hip dislocation, and found that 14/17 patients had anterior labral tears, 6/17 had posterior labral tears, and 16/17 had acetabular chondral damage. All had femoral chondral damage and ligamentum teres injuries, and 14/17 had intra-articular fragments. Philippon et al. (2009) reported the arthroscopic findings of 14 professional athletes following non-fracture traumatic hip dislocation. The mean time to surgery was 125 days (range, 0–556 days). All patients had labral tears and chondral defects; two had isolated femoral head chondral defects, six had isolated acetabular chondral defects, and six had chondral defects on both surfaces. Loose osteochondral fragments and partial or complete ligamentum teres tears were found in 11 patients. It was concluded that traumatic non-fracture dislocation is often accompanied by a variety of intra-articular hip joint pathologies, the most common being labral, chondral, intra-articular loose fragments and ligamentum teres disruption (Philippon et al. 2009). Although these studies were not related to arthroscopic fixation after hip trauma, they show the potential advantage of arthroscopic-assisted fixation of the dislocated hip with acetabular fracture and the treatment of accompanying intra-articular hip pathologies. With the use of hip arthroscopy in trauma, certain types of fractures, such as Thompson-Epstein types 1 and 2, can be managed with a minimally invasive approach avoiding an extensive intervention that may be complicated by infection, blood loss, hip abductor muscle weakness, sciatic nerve palsy, or heterotrophic ossification. The minimally invasive approach provides earlier rehabilitation, better cosmetic results, and the opportunity to diagnose and treat accompanying intra-articular pathologies, which may be a cause of persistent hip pain and early-onset osteoarthritis (Byrd 1996; Kaempffe et al. 1991; Philippon et al. 2009).

Hip arthroscopy has its own risk of complications such as traction injuries to the sciatic nerve or pudendal nerve compression. However, surgeons must keep in mind that patients may be at additional risk of conventionally known risks due to the trauma, which is generally high-energy in nature. Bartlett et al. (1998) reported the first case of abdominal compartment syndrome while performing hip arthroscopy to remove loose bodies after acetabular fracture internal fixation. Arthroscopic fluid extravasation through the fracture site was blamed for abdominal compartment syndrome that presented as cardiopulmonary arrest. After this case, abdominal compartment syndrome after hip arthroscopy in non-trauma cases has also been reported (Fowler and Owens 2010; Ilizaliturri 2009; Ladner et al. 2010; Newman et al. 2015). To avoid this complication, Park et al. (2016) recommended that pump pressure be kept at 30–60 mmHg and operation time should not exceed 90 min, in addition to close monitoring of intraoperative and postoperative abdominal distension, core body temperature, and hemodynamic stability. Reduction of core temperature is another issue that requires attention, especially in trauma patients, and when irrigation fluid exceeds 30 liters. Warmed saline usage in hip arthroscopy may be selected to reduce the risk (Newman et al. 2015). Positioning of the patient and traction of the affected limb for hip arthroscopy are other problems encountered in trauma patients.

26.4 Conclusion

In conclusion, hip arthroscopy in trauma patients can be used to repair acetabular fractures, however, with limited indications, such as Thompson-Epstein types 1 and 2, fractures with the advantage of minimal invasiveness in contrast to open arthrotomy and direct visualization and reduced exposure to radiation in contrast to percutaneous acetabular fracture fixation under fluoroscopic guidance. Moreover, there is a good opportunity to remove loose bodies, which have not been diagnosed preoperatively, and to diagnose and treat other intra-articular pathologies that may cause residual hip pain and possibly lead to early osteoarthritis.

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Part V

Arthroscopic Management of Knee Fractures

27

Arthroscopy-Assisted Retrograde Nailing of Femoral Shaft Fractures

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27.1 Arthroscopy-Assisted Retrograde Femoral Nailing of Femoral Shaft Fractures

Retrograde nailing is used for supracondylar osteotomies and supracondylar or distal fractures of the femur (Acharya and Rao 2006). The indications for retrograde femoral nailing are expanding and include mid-shaft and supracondylar femoral fractures concomitant with tibial shaft fractures, bilateral femoral fractures, low supracondylar femur fractures, obesity-related fractures, periprosthetic femoral fractures (related to both hip and knee arthroplasties), ipsilateral femoral neck and shaft fractures, ipsilateral femoral shaft and acetabular fractures, and fractures during pregnancy (Born et al. 2006). However, due to significant fracture displacement, comminution, and intra-articular extension, ideal fixation is often difficult to maintain (Clement et al. 2011; Gliatis et al. 2006). Consequently, increased attention has been directed to the entry point as the key to achieving a good reduction and better surgical results. Additionally, during retrograde nailing, an arthrotomy is required for nail insertion, which means that an uninjured knee joint is violated. Guerra et al. (1995) described arthroscopy-assisted retrograde femoral nailing to address these issues.

27.1.1 Advantages

The potential benefits of an arthroscopic technique compared with a standard arthrotomy are associated with achievement of a fracture that is well aligned as a result of using a correct entry point; a smaller skin incision and, thus, rapid soft-tissue healing; early mobilization; early convalescence; shorter hospitalization; and earlier return to daily life.

Additional advantages are as follows: (1) treatment of concomitant intra-articular injuries such as chondral lesions, meniscus tears, cruciate ligament tears, eminentia fractures, Hoffa fractures, intercondylar T-fractures (Fig. 27.1), and patellar fractures, (2) ability to remove intra-articular loose bodies and debris, (3) avoidance or reduction of the negative effects of intraoperative radiation (fluoroscopy), and (4) ability to directly verify nail depth. Being aware of concomitant injuries will guide the surgeon in planning a second surgical session if needed or in setting up a postoperative rehabilitation program, which aims to effectively manage all detected injuries.

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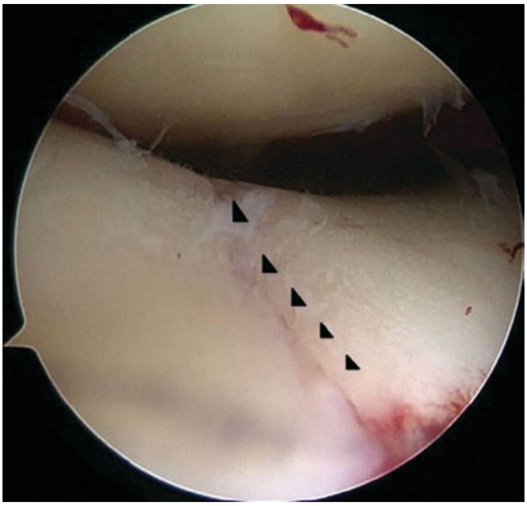

Fig. 27.1 A supracondylar femur fracture with articular extension after fixation with free screws (arrow heads)

Fig. 27.2 Position of the patient. A towel is placed under the knee to achieve 60° of knee flexion. This maneuver will aid in maintaining the alignment. A standard anterolateral arthroscopic knee portal is then established

27.1.2 Surgical Technique

Requirements:

- Fluoroscopy (to confirm alignment maintenance and correct proximal screw insertion)
- Radiolucent table
- Arthroscopy equipment

A tourniquet is not recommended. With the patient in supine, the knee should be in 60° of flexion to help maintain fracture alignment (Fig. 27.2). Standard anterolateral and anteromedial arthroscopic knee portals are used. Intra-articular hematoma and fibrin should be removed by a shaver to ensure good visualization of the fracture. Intra-articular injuries should be examined carefully.

Intra-articular fractures should be temporarily fixed with Kirschner (K-) wires at the beginning of the surgical procedure to secure sufficient bone stock prior to arthroscopy (Krause et al. 2016). With intercondylar T-fractures and comminuted metaphyseal fractures (AO 33-C1 and 33-C2), two or more K-wires should be placed at the medial and lateral condyles approximately 1 cm from the fracture line. The K-wires serve as “joysticks” that allow mobilization of the condyles. When anatomic reduction is completed, the K-wires should be pushed forward from one to the other condyle to ensure reduction of the distal femur fragment (Fig. 27.3).

The most important part of the procedure is to maintain alignment during nailing. Accordingly, rigid fixation should be maintained by one or two lag screws while avoiding possible interference with nail insertion by preserving a distance of 15 mm between the screws and the nail entry point (Fig. 27.4).

Following initial arthroscopic evaluation, a needle guide is used to determine the exact location of the skin incision and the direction of the guide-wire (Fig. 27.5). A 2 cm medial parapatellar incision is then made (Fig. 27.6).

Direct arthroscopic visualization is used to determine the intercondylar entry point, located 6 mm anterior to the origin of the posterior cruciate ligament (Fig. 27.6b, c). Femoral intramedullary insertion of a threaded guide-wire can be confirmed by anteroposterior and lateral views using fluoroscopy. On lateral knee radiography, nail insertion should be seen to start anterior to the Blumensaat line (Fig. 27.4).

Attention should be paid to any conditions that may result in compartment syndrome. Arthroscopic nailing is a safe procedure if the arthroscopic pressure does not exceed 50 mmHg. Another option is to establish (a third) suprapatellar arthroscopic portal to avoid high intra-articular pressure. Arthroscopy can be performed “dry,” especially in extra-articular fractures. In these “dry” arthroscopies, the risk of thermal necrosis can be minimized by delaying washing out the

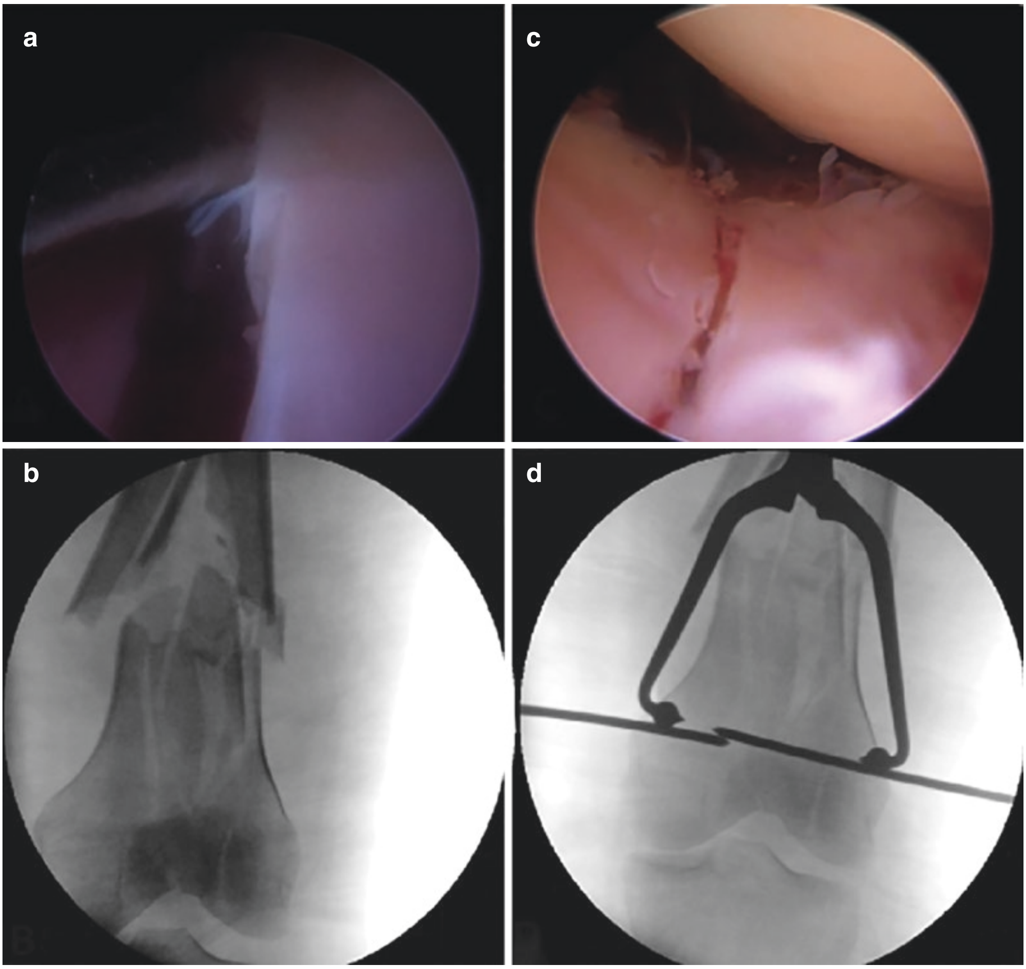

Fig. 27.3 A 25-year-old female sustained a AO 33-C2 distal femur fracture and a vertical patella fracture after a fall from a 4 m height. Reduction of the intra-articular fracture. (**a**, **c**) The fracture pattern under fluoroscopy and (**b**, **d**) intra-articular views

Fig. 27.4 A distance of at least 15 mm should be preserved between the Blumensaat line and the screws to avoid interference with nail insertion. On lateral knee radiograph, the ideal entry point for retrograde femoral nailing is anterior to the Blumensaat line

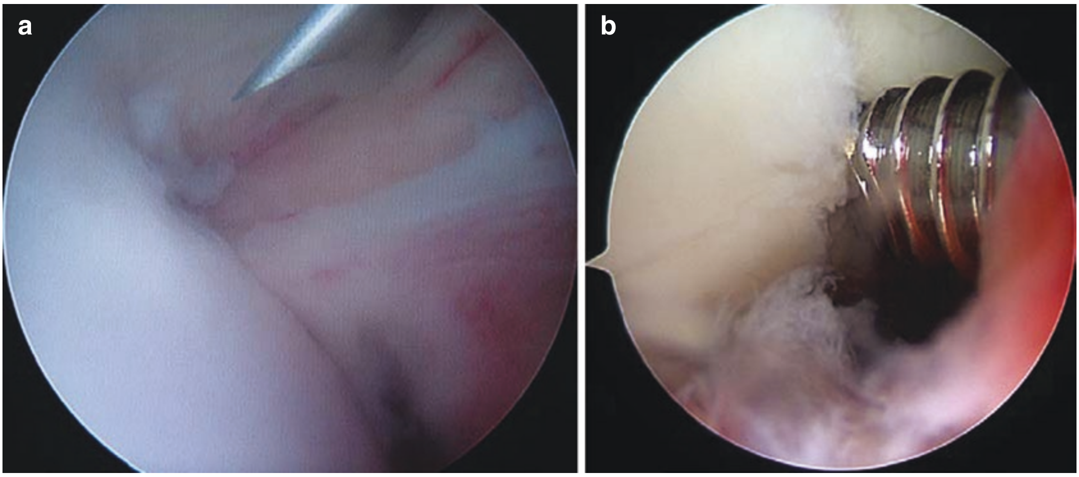

Fig. 27.5 Nail insertion. The exact direction and location of the entry point are determined via needle insertion

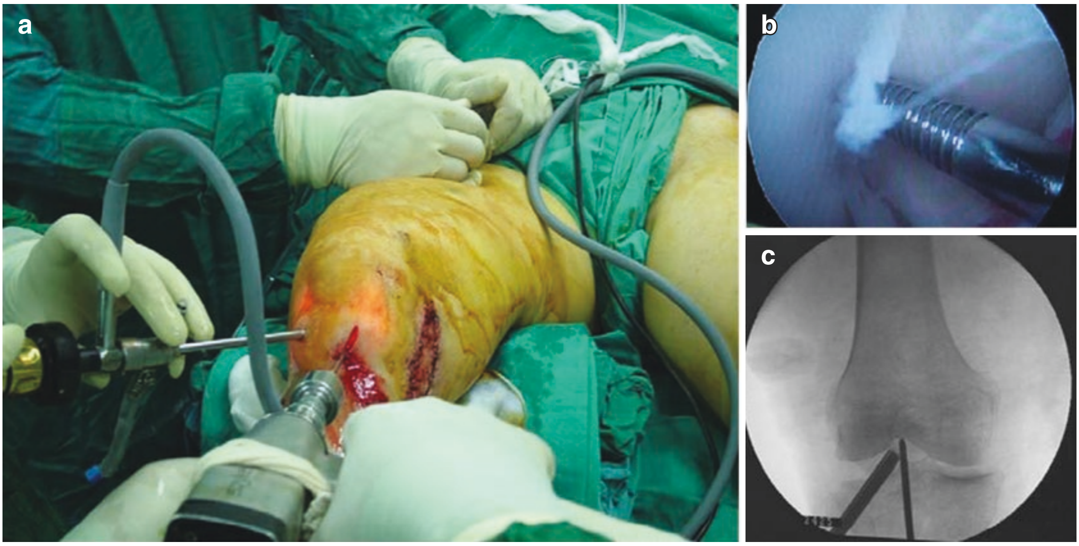

Fig. 27.6 A medial parapatellar incision for nail insertion (**a**) intramedullary femoral insertion of a threaded guide-wire, seen on the arthroscopy (**b**) and fluoroscopy (**c**) monitors

fluid from the knee until after the subchondral bone is drilled. In such cases, Hoffa's fat pad almost always tends to become swollen as a first reaction to the trauma, and shaving the fat tissue may not be sufficient to obtain an optimal view. To move the fat pad and achieve better visualization, sutures passed through both portals can be used. Pulling the sutures anteriorly creates enough area for surgeon to view the notch (Fig. 27.7).

Fracture reduction is maintained using routine methods. Intramedullary reaming of the femur is performed using a guide-wire. If needed, femoral alignment is maintained using either poller screws or provisional K-wires acting like Poller screws (Poyanli et al. 2016). After the ideal nail size is determined, it is inserted into the femur and then stabilized with screws. To prevent intra-articular nail migration, it should be initially locked using a distal screw. Free-hand screw insertion is facilitated by the use of fluoroscopy. Alternatively, fixation can be completed by intramedullary electromagnetic techniques, which will reduce radiation exposure. However, in that case, the proximal screw should be fixed first. Before insertion, paper alignment and rotation should be confirmed, and intra-articular screw penetration should be avoided.

After the insertion is completed, the nail depth is easily visualized (Fig. 27.8). Intra-articular debris (Fig. 27.9) resulting from intramedullary reaming should be removed using a shaver. As a thorough arthroscopic examination is not possible before fracture fixation, additional interventions, such as meniscus repair or microfracture to repair cartilage defects, are carried out after ensuring the safe position of the knee.

Fig. 27.7 Moving the Hoffa fat pad anteriorly by a suture passed through portals to achieve better arthroscopic view

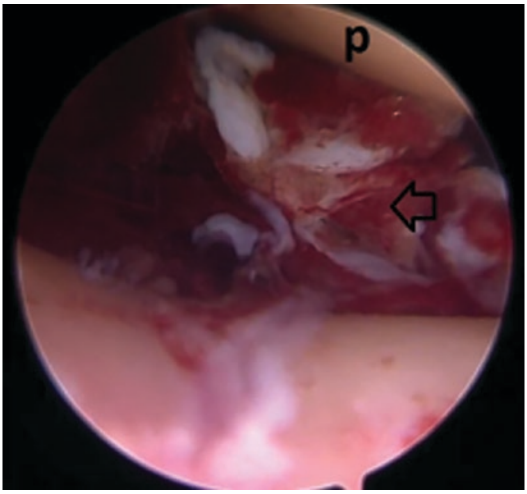

Fig. 27.9 Intra-articular debris (arrow) should be removed after the procedure (P: patella)

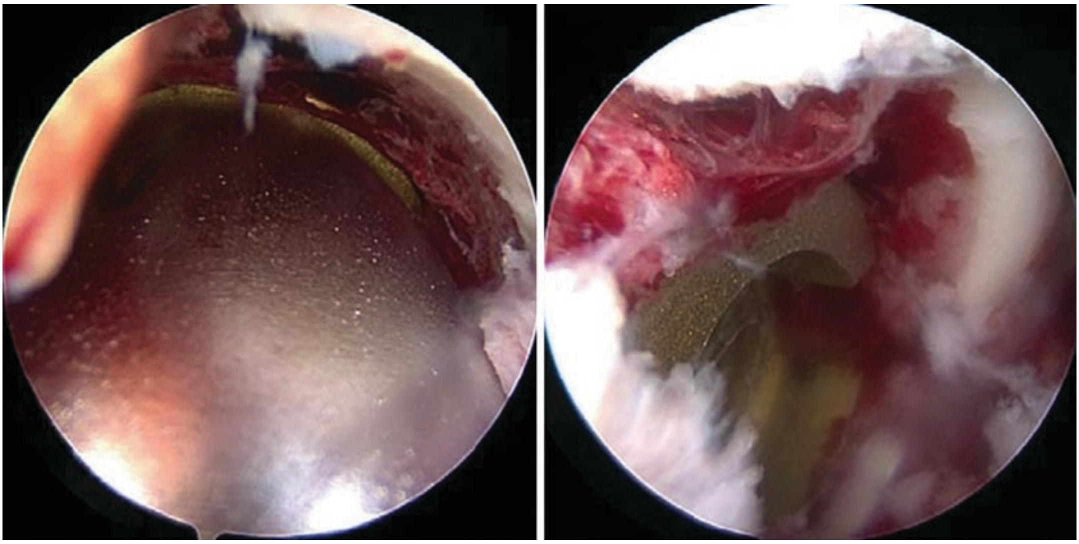

Fig. 27.8 Embedding of the nail should be checked by direct arthroscopic visualization

27.2 Arthroscopy-Assisted Removal of Retrograde Femoral Nail

Retrograde nailing is often claimed to be the cause of anterior knee pain (Acharya and Rao 2006; Clement et al. 2011). This can be confirmed or ruled out by removal of the nail. However, it is often unclear whether the nail was actually the cause of the pain. The most important part of nail removal is leaving at least one proximal screw in place before the removal apparatus is attached to the nail. Otherwise, the nail may move proximally in the femur. If the nail cannot be observed, its exact location under the articular cartilage can be determined fluoroscopically (Born et al. 2006). In these cases, arthroscopic debridement may be needed to excavate the nail.

27.3 Limitations

The surgeon should be aware of the risk of fluid extravasations through the nail hole and fracture site into the thigh. Although controversial, fluid extravasations may be related to increased compartment syndrome risk (Born et al. 2006). These complications can be avoided by being careful and paying attention to fractures that extend to the joint. Also, after treating an intra-articular pathology by traditional arthroscopy, "dry" arthroscopy may be performed for nail insertion. As noted above, the risk of thermal necrosis can be minimized by delaying washing out the fluid from the joint until after the subchondral bone is drilled. However, as long as the intra-articular pressure increase is kept to a minimum during the arthroscopic procedure, the development of compartment syndrome is unlikely. After joint debridement, and overall assessment of the joint, precise reduction with previously added "joysticks," and final nail insertion can be performed with ease. As a last step, closing the terminal hole of the nail using an end cup will prevent fluid extravasation and may simplify its removal if needed (Fig. 27.10).

27.4 Conclusion

The treatment of concomitant intra-articular injuries, avoidance or reduction of the negative effects of intraoperative radiation (fluoroscopy), and the ability to verify nail depth are the main advantages of arthroscopy-assisted retrograde femoral nailing versus standard arthrotomy. Along with this, surgeons should not forget about the limitations. In conclusion, based on its advantages and disadvantages, arthroscopic retrograde femoral nailing is a safe and minimally invasive technique for the repair of femoral fractures, especially in patients with concomitant intra-articular injuries.

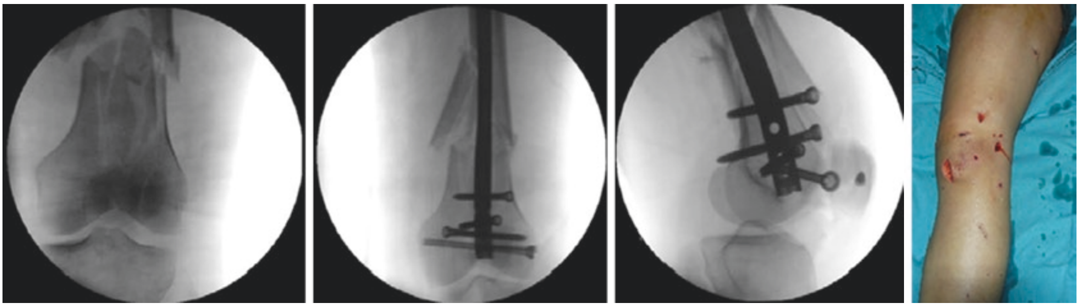

Fig. 27.10 Preoperative and postoperative fluoroscopic views are seen. Skin incisions indicate a successful treatment of a distal femoral fracture by minimal invasive technique (note the vertical patellar fracture reduced and fixed at the same session with a cannulated screw)

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28 The Distal Femur Fractures

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28.1 Introduction

Femoral condylar and supracondylar fractures are generally caused by high-energy injuries in young and middle-aged patients and by low-energy injuries in elderly patients suffering from osteoporosis. Low-energy injuries in the elderly are increasing, reflecting societal aging. Nonsurgical treatment used to be prioritized in the elderly due to difficulties associated with anatomical reduction, poor internal fixation quality, and difficult fracture reduction maintenance. Recently, internal fixation devices such as the AO 95-degree blade plate (ABP) and the retrograde intramedullary nail (IMN) (Leung et al. 1991) have been developed for use with this patient population. The development of new fixation devices has improved treatment outcomes and increased the use of surgical management methods over nonsurgical approaches in this population (Butt et al. 1996).

28.2 Classification

In this chapter, intercondylar fractures (33-type B) and supracondylar fractures (33-type C) are mainly described according to the AO/OTA classification (Marsh et al. 2007). In the AO/OTA classification of the distal femur (33), type B1–type B3 and type C1–type C3 fracture patterns are considered difficult to treat.

Type B is subdivided into three subtypes according to the coronal and sagittal image of the fracture line. Type B1 is a lateral condylar fracture in the coronal plane. Type B2 is a medial condylar fracture in the coronal plane. Type B3 is called a "Hoffa fracture," a relatively rare type with a fracture line in the sagittal plane (Fig. 28.1a, b) (Hoffa 1904).

Type C is a combination of supracondylar fracture and intercondylar fracture. Type C1 is a relatively simple fracture without a third fracture fragment. The fracture lines of type C1 are T or Y shaped. Type C2 is a comminuted fracture around the supracondylar part. Type C3 is a comminuted fracture around the articular surface.

28.3 Treatment

Fractures of the distal femur remain a daunting challenge. The principle of management has been surgical since the 1970s, and treatments have been developed to limit complications such as

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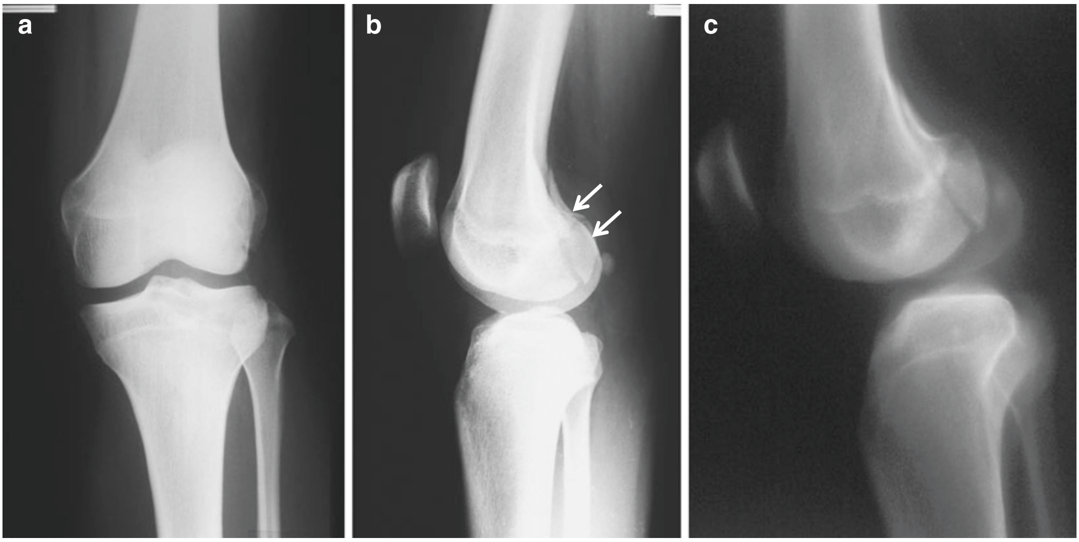
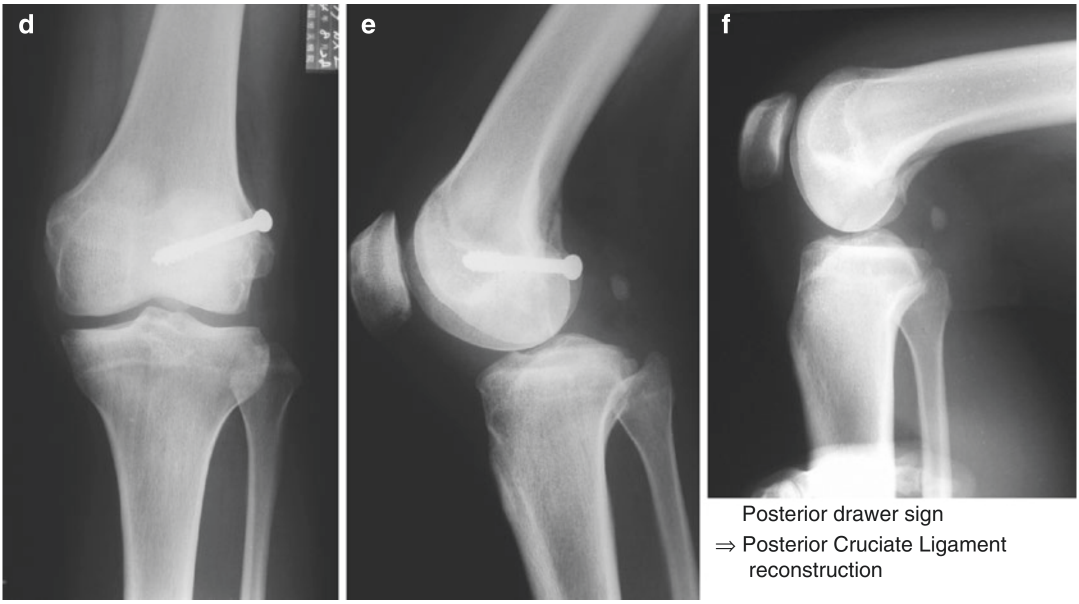


The first examination

tomogram



Posterior drawer sign
⇒ Posterior Cruciate Ligament reconstruction

Cancellous screw fixation

Fig. 28.1 A 28-year-old female. AO/OTA type B3 (Hoffa). The coronal fracture (X-rays (**a**, **b**) and tomogram (**c**)). The fracture was treated with cancellous screw (**d**, **e**). The posterior cruciate ligament was ruptured (**f**)

joint stiffness, nonunion, and infection. Recently, two types of fixation devices have often been used for the distal femoral fracture: plate fixation and retrograde IMN fixation. In principal, retrograde IMN fixation is a soft tissue-friendly approach by closed procedure. Plate fixation has also achieved progress as a soft tissue-friendly approach by minimally invasive percutaneous plate osteosynthesis (MIPPO) and with transarticular approach retrograde plate osteosynthesis (TARPO). Meta-analyses have found no difference between the two implants in minimally invasive procedures (Griffin et al. 2015; Piétu and Ehlinger 2017). The main advantage of plate fixation is its versatility, whereas retrograde IMN fixation can be impossible in cases of certain hip or knee prostheses, compound articular fractures, or medullary canal obstruction by fixation material (nail, stem, screw, etc.). The latest studies have concluded that the surgeon's experience is more relevant to the outcome than any particular implant (Hierholzer et al. 2011; Kregor et al. 2004; Lal et al. 2011; Schütz et al. 2005; Zlowodzki et al. 2006). In this text, these application and procedures are described according to the fracture classification.

1. Nonsurgical treatment

   Nonsurgical treatment using a cast brace, which is a functional orthosis therapy, was one of the recommended treatments (Fig. 28.2) prior to the development of new fixation devices. The cast treatment reported by Mooney et al. (1970) is a safe treatment that can lead to bone fusion while maintaining knee joint function. After 5–6 weeks of traction or casting, when the fracture shows radiographic signs of healing, a cast brace can be useful in allowing early range of motion and training. Depending on radiographic findings, partial weight-bearing may also be initiated at this time. When the patient can bear full weight, without pain, the use of the cast brace can be discontinued. Cast brace use can be particularly helpful for fracture management in elderly patients because of its safety and the possibility of knee joint function preservation. This conservative treatment might still be useful even now for patients with complicated condylar fractures after unsuccessful surgery.
2. Femoral condylar fracture (types B1~B3)
   (a) Treatment for types B1 and B2

   In type B1 and type B2 fractures with a small degree of displacement, conventional cancellous screws (occasionally

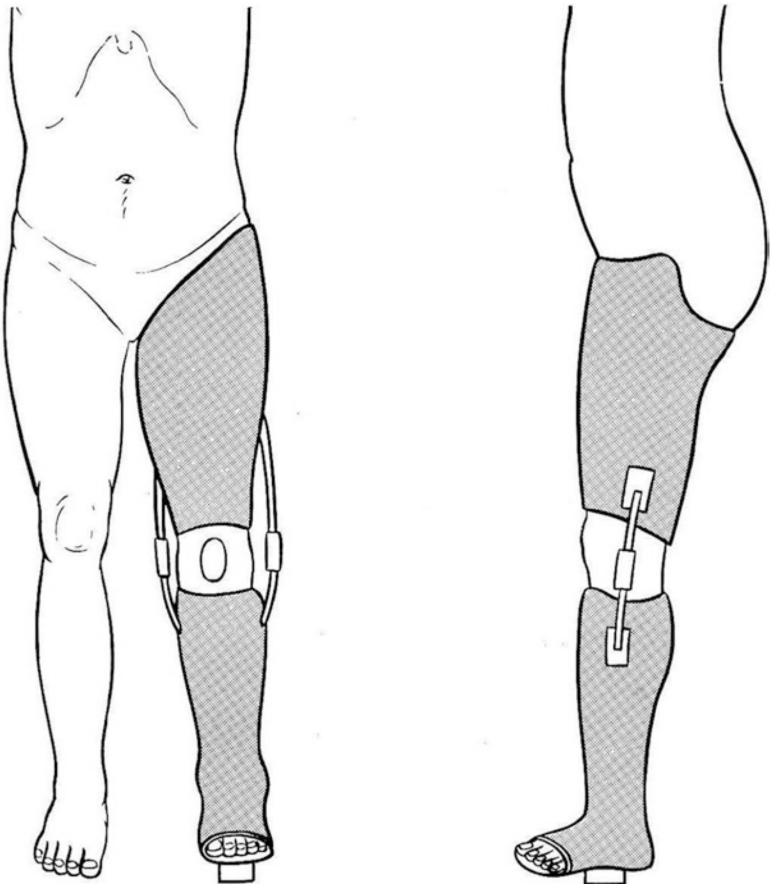


Fig. 28.2 Functional brace (cast brace)

with a washer) are often used. In cases with large bone fragments or with a fracture line that extends proximally, this type of fixation with conventional screws is insufficient and often leads to secondary displacement. There are reports that have recommended locking compression plate (LCP) fixation to prevent such displacement. Intramedullary nail use enables firm fixation and allows both early knee joint range of motion training and early partial weight-bearing (Fig. 28.3a, b).

(b) Treatment for type B3

This fracture is relatively rare and occurs after high-energy trauma such as traffic accidents. The mechanism of injury is that the knee joint is mildly flexed in varus or valgus when the high-energy force from the tibial axis is transmitted to the relatively fragile posterior part of the femoral condyle (Smillie 1978). This strong external force often results in a type B3 fracture in combination with ligament injury of the knee (Fig. 28.1).

In the case of fracture displacement, both exact articular surface reduction and strong internal fixation should be strived for in order to prevent osteoarthritis.

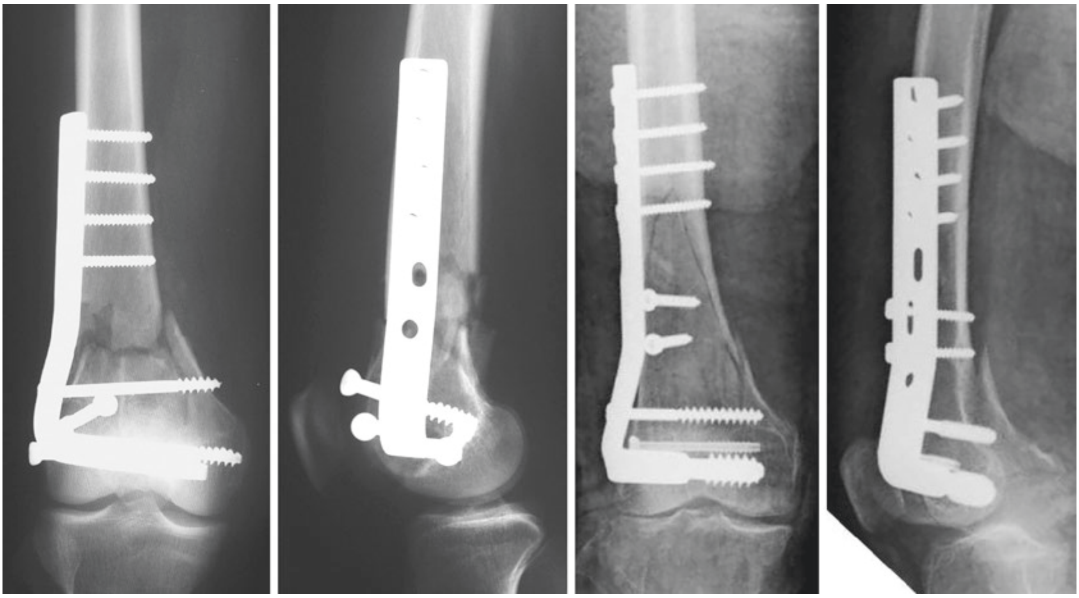
3. Femoral supracondylar fracture (types C1~C3)

Either an AO 95-degree blade plate (ABP) or dynamic compression screws (DCS) have been traditionally used for these types of fractures (Fig. 28.4). The ABP has technical difficulties in terms of blade insertion. The DCS is limited in that it requires extensive soft tissue

An 84-year-old female.

A 72-year-old female.

Fig. 28.3 AO/OTA type B2. Both fractures were treated with IMN. (**a**) An 84-year-old female. (**b**) A 72-year-old female



AO/OTA type-C3 (A 38-year-old male)
AO 95-degree blade plate (ABP)

AO/OTA type C2 (A 79-year-old female)
Dynamic Compression Screw (DCS)

Fig. 28.4 Conventional method. (**a**) AO/OTA type C3 (A 38-year-old male). AO 95-degree blade plate (ABP). (**b**) AO/OTA type C2 (A 79-year-old female). Dynamic compression screw (DCS)

release associated with lag screw insertion. With DCS use, fracture re-displacement and delayed union are sometimes experienced in middle-aged and elderly patients with osteoporosis. In recent years, the LCP method and the IMN methods have been used more often than the aforementioned ABP and DCS fixation devices. The choice between LCP and IMN methods is primarily dependent on fracture type and patient age. The LCP is primarily used for the young and in adult patients who need precise articular joint surface repair and articular cartilage preservation (Fig. 28.5). In contrast, IMN fixation is mainly used for fractures in elderly patients due to its lower invasiveness and easy axis alignment reduction (Fig. 28.6). Intramedullary nailing methods are generally used in cases that do not require precise articular surface reduction, especially in type C1 and type C2 fractures, while LCP is recommended in cases that require two or more transverse locking screws to be inserted into the distal bone fragments.

Good results have been reported for both the LCP and IMN methods, and some studies have reported similar results (Markmiller et al. 2004). Heiney et al. (2009) reported that IMN is superior to LCP from a biomechanical perspective. Other reports have recommended the IMN method for elderly patients because of its lower surgical invasiveness, shorter surgical time, and less bleeding. In a prospective study comparing LCP and IMN, Tornetta et al. (2013) reported that although there was no statistically significant difference, the IMN method was superior due to a lower risk of delayed union and deformation and lower postsurgical infection rates.

Among patients who are more than 55 years of age, we have used IMN for C1 and C2 fractures (Fig. 28.6) and some cases of C3 fractures with a minimally displaced intercondylar fracture (Fig. 28.7). We suggest that when IMN can hold two or three peripheral screws to secure both condyles, it should be the primary fracture fixation option in this patient group.

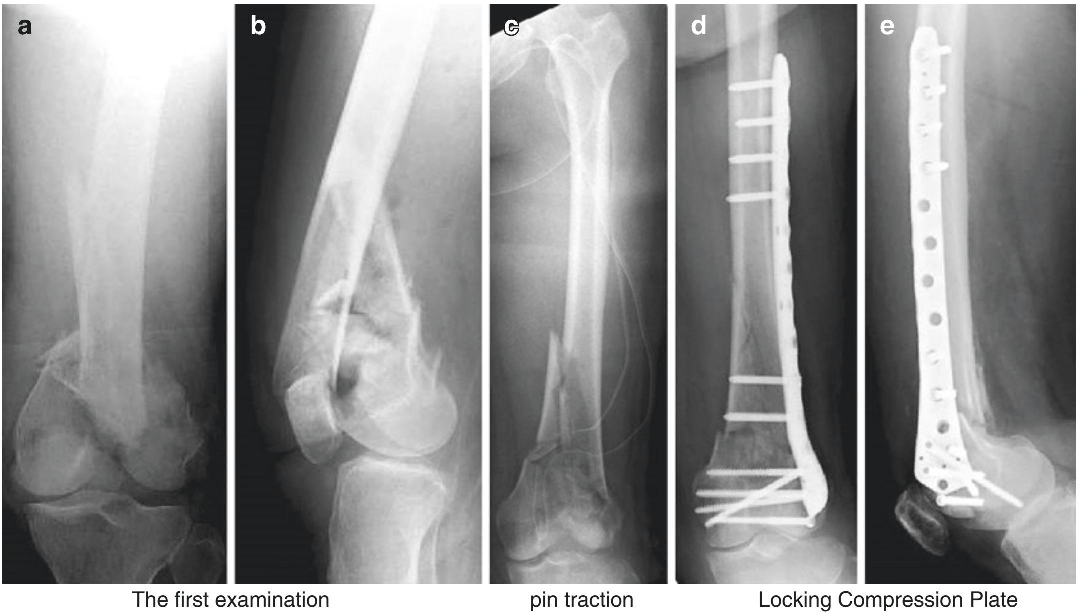


Fig. 28.5 A 66-year-old female. AO/OTA type C3 (open fracture). Type C3 supracondylar fracture (**a**, **b**). Fracture was treated with a locking compression plate (**c**, **d**). (**a**, **b**) The first examination. (**c**) Pin traction. (**d**, **e**) Locking compression plate

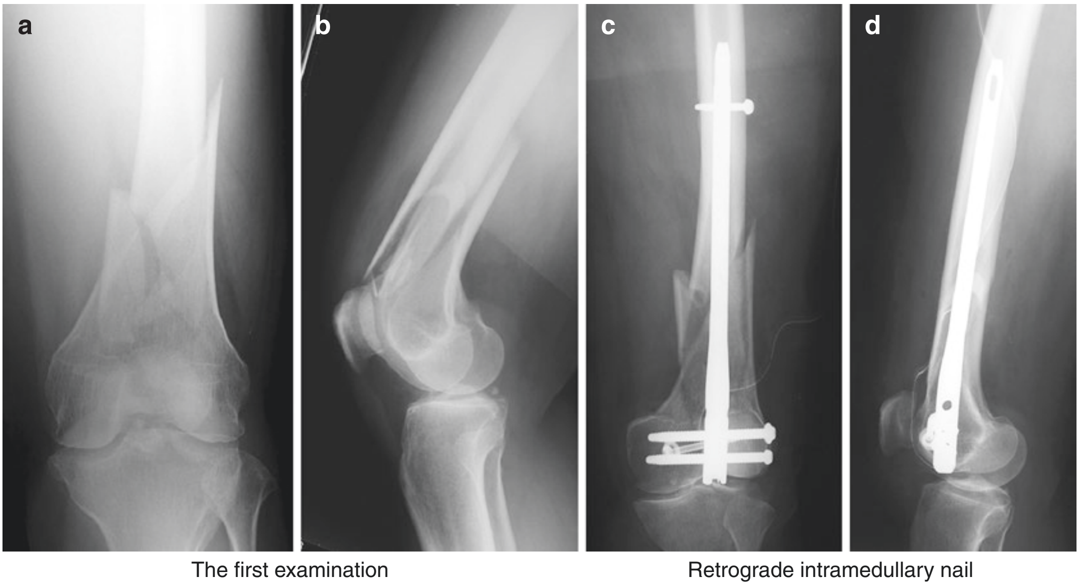


Fig. 28.6 A 64-year-old female. AO/OTA type C2. Supracondylar femoral fracture (**a**, **b**). The fracture was treated with an intramedullary supracondylar nail. (Stryker T2) (**c**, **d**). (**a**, **b**) The first examination. (**c**, **d**) Retrograde intramedullary nail

Fig. 28.7 A 65-year-old female. AO/OTA type C3. IMN can be applied even for C3 fractures with a less displaced intercondylar fracture

28.4 Preferred Intramedullary Nailing Surgical Technique

Surgeons should use radiographs and templates to predict the appropriate length and diameter of the IMN. The IMN length should extend beyond the femoral isthmus, and the diameter should be sufficient to occupy the bone marrow. Computed tomography (CT) is useful for confirming proper IMN length and diameter.

The operation is performed under either general or spinal anesthesia. The skin incision is expanded from an initial medial para-patellar approach through the medial margin of the patella. Then, the intra-articular knee joint structures are well exposed. The IMN entry point is located approximately 0.5–1.0 cm anterior to the femoral posterior cruciate ligament insertion as confirmed with fluoroscopy. This point is located at the front edge of Blumensaat's line and is an important point for reduction. Following this, a guidewire is inserted. After reaming and guidewire placement an IMN of maltinational thickness should be used. To achieve optimal fracture fixation strength, attention should be paid to using an IMN of sufficient length.

Selection of the IMN type is important. The IMN should be capable of holding more than two screws to stabilize the distal bone fragment. The T2 SCN (Stryker Corp., Kalamazoo, MI, USA), META Nail (Smith & Nephew, Memphis, TN, USA), and Phoenix Nail (Zimmer Biomet Inc., Warsaw, IN, USA) are all useful for managing distal fragments because more than three screws can be inserted within 40 mm from the joint line. In addition, the angular stability in both the T2 SCN and Phoenix Nail is important to improve fixation stability.

28.5 Arthroscopy-Assisted Reduction and Internal Fixation: Femoral Condylar Fracture (Type B3 Hoffa Fracture)

Coronal plane fractures of the distal femoral condyle (Type B3) are labeled as "Hoffa fractures" (Hoffa 1904). The distal fragment owing to no muscle attachment acts as a free lying, large, intra-articular bone piece. Conservative treatment has been associated with poor outcomes (nonunion, osteoarthritis, and stiff knee) (Papadopoulos et al. 2004; Zeebregts et al. 2000). Early anatomical reduction and internal fixation remains the treatment of choice. Arthroscopy-assisted reduction and internal fixation of these fractures with a minimally invasive procedure was first reported by Wallenbock and Ledinski (1993). This technique has been applied, and many reports have supported this procedure (Demirel et al. 2006; Ercin et al. 2013; Goel et al. 2016; McCarthy and Parker 1996; Stern 1996). Arthroscopy-assisted reduction and internal fixation is an option especially for this type of fracture. It should be borne in mind that multiple lag screw fixation after anatomical reduction is very important (Arastu et al. 2013), whether under arthroscopic or open surgery.

28.6 Conclusion

In treating intra-articular fractures, it is important to select a treatment method that minimizes knee joint dysfunction. Patient age, fracture type, articular cartilage preservation needs, and concomitant soft tissue damage need to be taken into consideration. Arthroscopy-assisted reduction and internal fixation is an option especially for Hoffa fractures.

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Eminentia Fractures

29

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29.1 Introduction

The surgical treatment of fractures of eminentia intercondylaris of the tibia is a controversial topic. Multiple techniques using different approaches, arthroscopic portals, and fixation methods have been described. Due to the limited literature on the clinical outcomes (Leeberg et al. 2014; Osti et al. 2016), there is a general lack of consensus in terms of the choice of the most effective technique. The aim of this chapter is to present the surgical technique to treat tibial eminentia fractures, using arthroscopic reduction and screw fixation.

29.2 Indications

Due to the difficulties associated with non-operative management, surgical reduction and fixation for type III fractures is recommended (Fig 29.1a–d). There is a high incidence of intermeniscal ligament or anterior horn of medial/lateral meniscus entrapment in knees that have sustained these fractures (Veselko et al. 1996).

In terms of type II fractures, closed reduction should be attempted; however, there is an up to 50% risk that this fracture type cannot be properly reduced, due to soft tissue entrapment (Kocher et al. 2004). Moreover, manipulation for closed reduction may convert a type II fracture to a type III fracture. The screw fixation technique presented here should be used when the fracture fragment is at least three times the size of the screw diameter.

29.3 Surgical Technique

29.3.1 Setup

The patient is positioned supine, with a tourniquet inflated. A lateral post is positioned 4 cm

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Fig. 29.1 CT scan of a displaced tibial spine avulsion: coronal view (**a**) and the 3D anterior reconstruction (**b**); sagittal view (**c**) and lateral 3D reconstruction (**d**)

above the patella to allow the leg to hang free from the operating table to allow stress provocation. A fluid pump is not routinely used. A medial suprapatellar portal is used for water inflow, while high anterolateral and standard anteromedial portals are used for the surgical instruments.

The hemarthrosis is evacuated using a shaver through the anteromedial portal. During this stage, the ligamentum mucosum and part of the infrapatellar fat pad are resected to allow adequate visualization (Fig. 29.2a). After the hematoma has been evacuated, it is possible to inspect the joint for any other intra-articular lesions that should be addressed (Feucht et al. 2017). Care should be taken to check the condition and integrity of the anterior cruciate ligament (ACL) and the status of the articular cartilage and menisci, especially the anterior root of the lateral meniscus that could be avulsed with the spine.

29.3.2 Fracture Reduction

Turning the optics anteriorly, the inter-meniscal ligament is identified to check if any fracture fragment interposition is present. In such eventuality case, the probe is introduced from the anteromedial portal to move the inter-meniscal ligament allowing fragment reduction. The inter-meniscal ligament should be resected only in cases where it is impossible to disengage the entrapment. The fracture fragment is elevated, and the residual blood clot and debris are removed from the fracture bed with a shaver or small curette (Fig 29.2b). The fracture can then be reduced into its bony bed using a probe inserted from the anteromedial portal (Fig. 29.3a, b). Slight over-reduction of the fracture fragment is recommended.

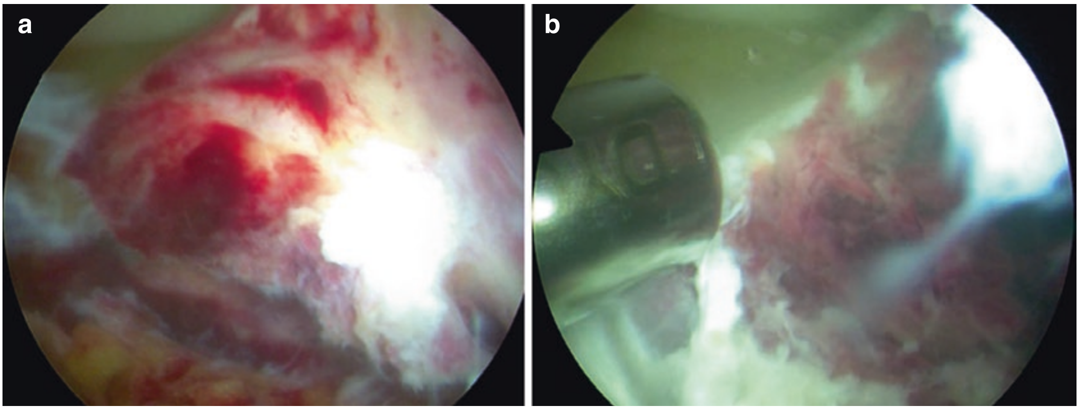

Fig. 29.2 Arthroscopic view from the standard anterolateral portal: the anterior cruciate ligament insertion is detached from the tibia with a small bone fragment and retracted proximally. The fracture bed is filled with hematoma and blood clot (**a**). The bone fragment is elevated, and the hematoma is removed with a motorized shaver in order to allow fracture reduction (**b**)

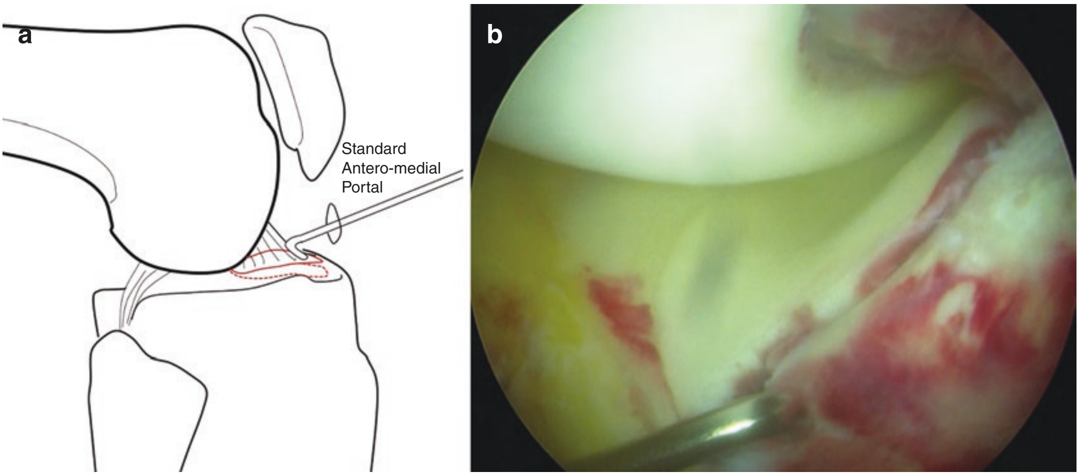

Fig. 29.3 A probe is inserted into the joint from the standard anteromedial portal and is used to reduce the fracture fragments (**a**). Positioning the knee at 60–70° of flexion helps the reduction maneuvers. In the arthroscopic view, it is possible to appreciate the minimal displacement of the fragment after the reduction maneuver (**b**)

29.3.3 Screw Fixation

With the leg hanging from the table at 60–70° of flexion, a high superomedial portal is created at the mid-patella level for screw insertion. An 18-gauge spinal needle directed perpendicularly to the tibial plateau may be used to verify correct portal placement. Fracture reduction is maintained using a probe, and a 1.4 mm guide wire directed from anterosuperior to posteroinferior is now inserted into the fracture fragment from the high anteromedial portal under fluoroscopic guidance (Fig. 29.4a–c). Care must be taken to avoid inadvertent posterior advancement of the guide will causing neurovascular damage or passing through the metaphyseal growth cartilage in skeletally immature patients. This may lead to growth disturbances. A measuring device is used to determine correct screw length; a 4.0 mm partial threaded cannulated screw (Rondò, Citieffe, Calderara di Reno, Bologna, Italy) is inserted over the guide wire to obtain good bone compaction (Fig. 29.5a). A screw with self-drilling and self-tapping features is recommended. Additionally, the use of an adjustable washer helps to enlarge the compression contact area (Fig. 29.5b). Once adequate fixation is obtained, guide wires are removed, and the knee

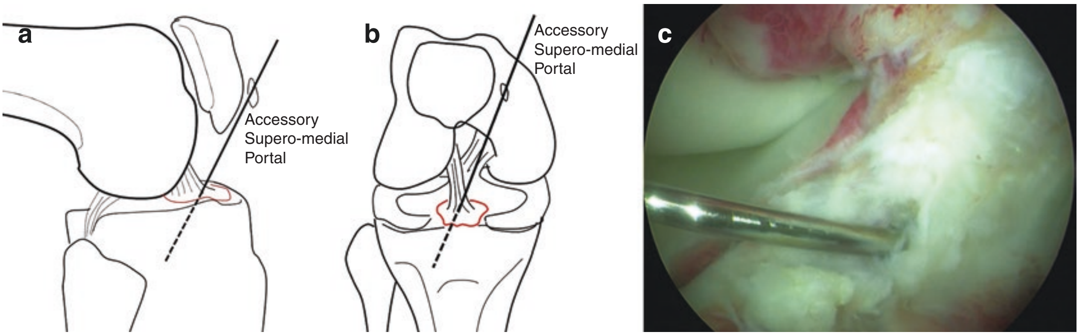

Fig. 29.4 A high anteromedial portal is created at the midportion of the patella, and a 1.4 mm wire is inserted perpendicular to the fracture. The direction of insertion should be from anterior to posterior (**a**) and from medial to lateral (**b**). In the arthroscopic view, it is possible to appreciate the wire maintaining the reduction (**c**)

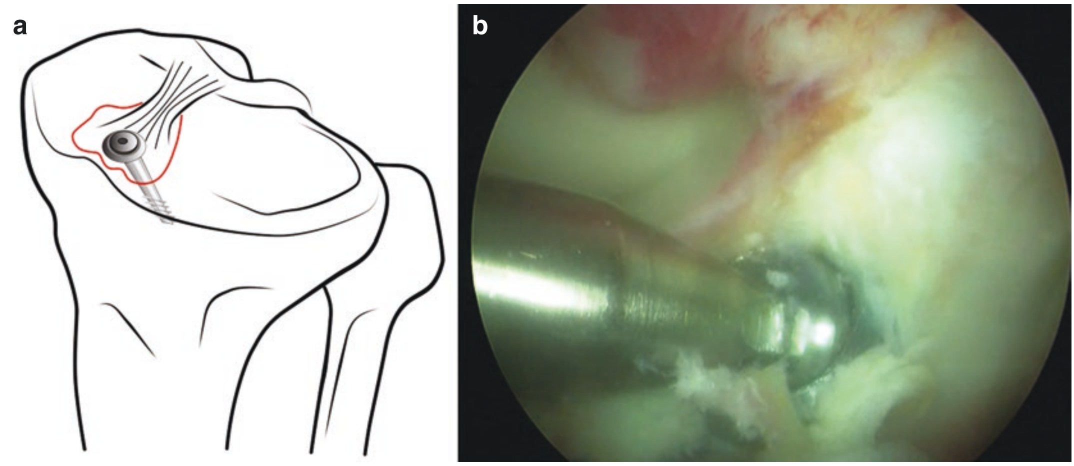

Fig. 29.5 The 4.0 mm partial threaded cannulated screw is inserted over the guide wire and tightened. The use of an adjustable washer enlarges the fracture site compression contact area. This helps maintain the reduction and avoid fragment disruption (**a**). The screw could be advanced further until the washer disappears with the soft tissue, in order to allow better compression on the fragment (**b**)

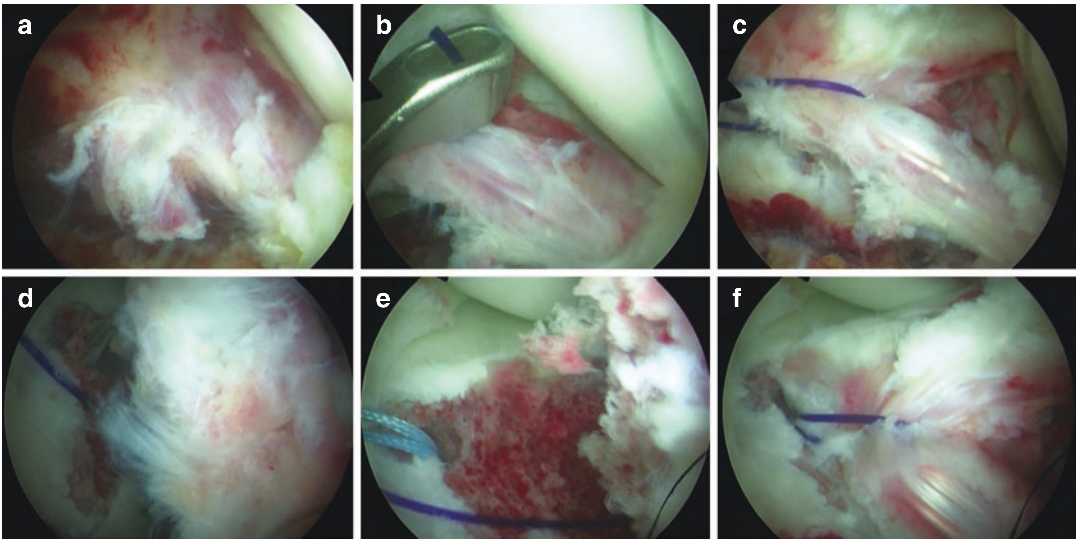

Fig. 29.6 The anterior root of lateral meniscus is avulsed from its anatomical insertion with a bone fragment of the tibial spine (**a**). A Caspari clamp is used to pinch the meniscal root (**b**) and pass a #2 PDS stitch (**c**). A K-wire is inserted from the anteromedial tibia directed through the anatomical insertion of the anterior root where the bone fragment is avulsed (**d**), and a shuttle suture is passed through the tibial tunnel to retrieve the PDS suture (**e**). Pulling the suture through the tibial tunnel, it is possible to reduce the bone fragment and the meniscal root in its anatomical location (**f**)

is gently moved through the full range of motion, and terminal extension is verified (Fig. 29.6). The arthroscope is then used to confirm that femoral notch impingement is not present. In the case of anterior horn of lateral meniscus avulsion, we recommend an arthroscopic transosseous reinsertion in order to avoid meniscal extrusion and loss of its function. Since the anterior horn of the lateral meniscus and the ACL shares the same insertion on the tibia, they could be both avulsed. Therefore, after ACL fixation, a 3 mm K-wire is used to drill a tunnel directed to the anatomical insertion of the lateral meniscus anterior horn. Then, a Caspari clamp is used to pass one or two #2 PDS sutures in the anterior horn, which are retrieved through the tibial tunnel and sutured to the anterior tibial periosteum or secured to the cortex with a button (Fig. 29.6a–f). Finally, a suction drain is inserted, and a knee brace locked in full extension is applied.

At the end of the procedure, it is possible to obtain a firm reduction and fixation of ACL and lateral meniscus from the initial displacement (Fig. 29.7a) to their anatomical location (Fig. 29.7b).

29.4 Rehabilitation

The suction drain is removed 24 hours postoperatively, and the patient is allowed to start passive knee range of motion exercises (Thaunat et al. 2016). The patient starts partial weight-bearing on day 3 postoperatively with a knee brace locked in full extension. This gradually increases to full weight-bearing over the next 4–6 weeks. The patient is encouraged to return to routine activities of daily life by 8 weeks post-surgery. Patients can resume participating in contact sports within 6–8 months after surgery.

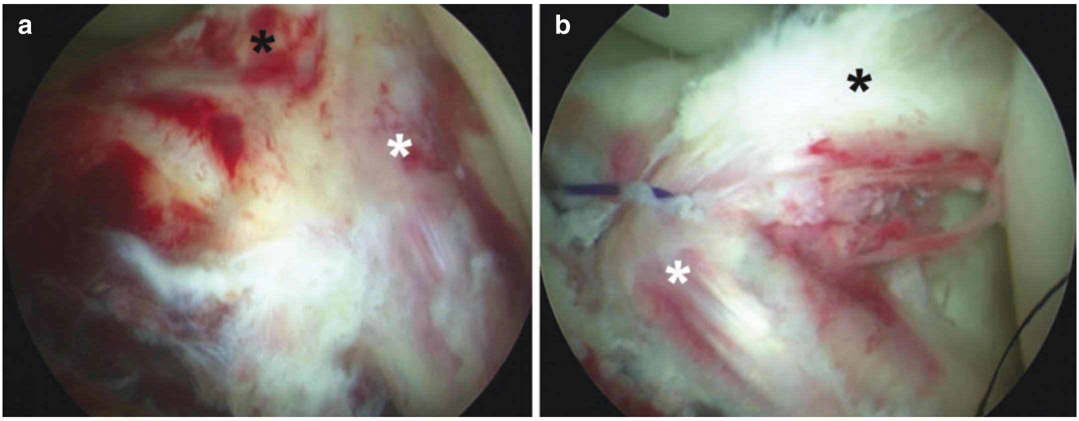

Fig. 29.7 In the initial arthroscopic view, the anterior cruciate ligament (black asterisk) is displaced proximally, and the anterior root of the lateral meniscus is elevated (white asterisk) (**a**). After surgical reduction and fixation, both the anterior cruciate ligament (black asterisk) and the anterior root of lateral meniscus (white asterisk) are in their anatomic position (**b**)

29.5 Conclusion

The arthroscopic treatment of spine avulsion represents a minimally invasive approach which could both restore knee stability and maintain the native ACL, with its innervation and proprioception. Moreover, the arthroscopic approach could be useful to detect and address intra-articular concomitant lesions such as meniscal anterior root avulsion. However, technical skills are required due to the possibility of spine fragmentation and multiple concomitant lesions and the presence of growth plate in skeletally immature patients.

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Eminentia Fractures: Transquadricipital Approach

30

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30.1 Introduction

Since the first description of tibial eminentia fractures by Poncet (1875), the interest for their diagnosis and management has increased markedly. The tibial epiphysis ossification process that occurs during adolescence makes this the weakest anterior cruciate ligament component (ACL) among this age group (Accousti and Willis 2003; Beaty and Kumar 1994; Gans et al. 2013; Kendall et al. 1992; Wiley and Baxter 1990). They may result from contact or noncontact injury mechanisms, following low- or high-energy trauma in children and adults, respectively. These lesions have been regarded as the pediatric bony equivalent of the ACL mid-substance rupture in adults; and their incidence in adults has been increasing (Hargrove et al. 2004; Kocher and Micheli 2001; Luhmann 2003).

Although intercondylar tibial eminentia fractures are still relatively rare, their frequency has been increasing. Importantly, these injuries should be considered following all traumatic knee injuries that lead to knee hemarthrosis in both children and adults. In this chapter, the classification, clinical evaluation, and treatment methods of tibial eminentia fractures will be summarized. Details about the technical aspects and perceived advantages of the transquadricipital tendinous portal technique of arthroscopic fixation are presented (Doral et al. 2001).

30.2 Clinical Evaluation and Classification

Patients with tibial eminentia fractures primarily complain of knee pain, effusion, impaired knee range of motion, and limited lower extremity function.

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In terms of imaging modalities, plain radiographs, computed tomography (CT), and magnetic resonance imaging (MRI) are all useful. Anteroposterior, lateral, and tunnel views are three essential radiographic views that should be initially used. Although plain radiographs are generally enough to diagnose the fracture, CT should be performed if there is any doubt about the diagnosis and extent of the injury. Additionally, MRI is used for two purposes: first, to confirm a fracture and, second, to evaluate the presence of any associated intra-articular pathology (soft tissue interposition, meniscus tear, etc.). Although arthroscopy is not the primary diagnostic tool, it is important for the evaluation of surgical management.

The most frequently used classification system for tibial eminentia fractures is the Meyers and McKeever (1959) classification modified by Zaricznyj (1977).

30.3 Management

Tibial eminentia fracture treatment strategies have evolved from a nonsurgical approach to the use of arthroscopic repair approaches (Gans et al. 2013; Meyers and McKeever 1959; Osti et al. 2016; Parikh et al. 2014). Current strategies based on fragment displacement are summarized in Table 30.1. There are two important questions that need to be answered in future studies. The first issue is whether a surgical or nonsurgical approach is best for type II lesions. Secondly, which is the best surgical fixation method? Moreover, untreated tibial eminentia fractures may lead to osteoarthritis as well as residual anterior knee laxity. However, the objective finding of residual anterior knee laxity often does not correlate with functional outcome (Lafrance et al. 2010; Leeberg et al. 2014).

Table 30.1 Current management of tibial eminentia fractures according to the Meyer and McKeever classification modified by Zaricznyj

Classification types	Treatment method
Type I	Nonsurgical treatment
Type II	Nonsurgical if closed reduction is anatomical Surgical if closed reduction is nonanatomical
Type III	Surgical
Type IV	Surgical

30.3.1 Nonsurgical Treatment

All type I and well-reduced type II tibial eminentia fractures can be treated nonsurgically (Atay et al. 2002; Bakalim and Wilppula 1973; Iborra et al. 1999; Lafrance et al. 2010; Meyers and McKeever 1970). Nonsurgical treatment is performed with knee immobilization with the application of a cast, splint, or brace with the knee positioned at up to 30^0 knee flexion for approximately 4 weeks. Hemarthrosis should be aspirated before immobilization. Although successful results with nonoperative treatment for type III fractures were reported by Molander et al. (1981) in the past, nonsurgical management is not currently recommended in displaced type II and higher grades.

30.3.2 Surgical Treatment

Nonanatomically reduced displaced type II and higher-grade tibial eminentia fractures and those that produce mechanical knee symptoms (e.g. menisci, fat pad, inter-meniscal ligament, etc.) are usually treated surgically. With regard to tibial eminentia fracture reduction, novel arthroscopic techniques have largely replaced arthrotomy (open, mini-open). Theoretical advantages associated with an arthroscopic-assisted reduction approach include less soft tissue damage, better visualization and ease of fracture reduction, easy evaluation of adjacent intra-articular structures, easier loose body removal, minimal postoperative pain, short hospital stay, and low risk of postoperative knee joint stiffness. Also postoperative rehabilitation is facilitated. However, the evidence supporting this

Table 30.2 Fixation methods for tibial eminentia fractures

- Metallic implants
  - – Kirschner wires (Bale and Banks 1995; Bonin et al. 2007; Wiley and Baxter 1990)
  - – Steinmann pins (Jung et al. 1999; Sundararajan et al. 2011)
  - – Staples (Kobayashi and Terayama 1994)
  - – Bioabsorbable nails (Momaya et al. 2018)
  - – Metallic screws (antegrade or retrograde) (Ando and Nishihara 2003; Berg 1995; Doral et al. 2001; Lubowitz and Grauer 1993; Reynders et al. 2002; Van Loon and Marti 1991)
  - – Herbert screws (Wiegand et al. 2014)
  - – Anchors (metallic or absorbable) (In et al. 2008; Vega et al. 2008)
  - – Intra-articular button (Memisoglu et al. 2016)
- Sutures
  - – Nonabsorbable vs. absorbable (Brunner et al. 2016; Eggers et al. 2007; Hirschmann et al. 2009; Schneppendahl et al. 2013; Yang et al. 2005)
- Other devices
  - – TightRope, Meniscal Viper Repair System, meniscal arrows, ACL-aiming device, rotator cuff guide (RCG) device/suture (Faivre et al. 2014; Kluemper et al. 2013; Ochiai et al. 2011; Wouters et al. 2011)

technique is limited. Moreover, arthroscopic reduction and internal fixation requires greater surgical experience than open reduction and internal fixation, and it represents a technically more demanding approach. Further studies are needed to confirm the efficacy of the surgical approach (Gans et al. 2013; Lafrance et al. 2010; Osti et al. 2016).

The various techniques that have been used for tibial eminentia fracture fixation are summarized in Table 30.2. Currently, the two most common methods are suture and screw fixation, respectively. The transquadricipital tendinous arthroscopic approach will be explained in detail in this chapter.

30.4 Transquadricipital Tendinous Arthroscopic Approach

The surgical steps for this approach, originally described by Doral et al. (2001), are explained in detail as below.

30.4.1 Surgical Preparation

The standardized arthroscopic procedure may be carried out under general or regional anesthesia in the supine position.

30.4.2 Arthroscopic Evaluation of the Joint and Reduction of the Fracture

Initially, two anterior (anteromedial, anterolateral) and one midline of transquadricipital tendinous suprapatellar portals are used for surgical instruments and drainage, respectively. A surgical arthroscope of 4 mm in diameter, 30° or 70° (as needed), is used for visualization. Standardized arthroscopic evaluation of each knee joint compartment should be performed prior to fracture evaluation.

Following hematoma "debridement," the fracture site should be fully exposed. All interposed tissues (such as meniscus, fat pad, and intermeniscal transverse ligament) should be removed from the fracture site. Using an arthroscopic probe, the medio-lateral size of the intra-articular fragment is measured, and it is carefully reduced. In order to achieve successful fixation using this technique, the fracture should not be comminuted. To prevent loss of fracture reduction from ACL traction, the knee should not be flexed to 40° or more during fracture fixation.

Creation of the "Transquadricipital Tendinous Portal" and Reduction and Fixation of the Fracture (Fig. 30.1a, b)

Following fracture reduction, the "transquadricipital tendinous portal" is created using a midline approach, 1 cm above the superior patellar pole. After placement of a 4.5 mm arthroscopic cannula to protect the patellofemoral articular cartilage surfaces, one or preferably two, 1.25 mm diameter guidewires are used and located from the transquadricipital portal into the intercondylar eminence. Use of this portal allows vertical guidewire placement perpendicular to the fracture line. A 2.7 mm cannulated drill is advanced over the guidewire, and a self-tapping 3.5 mm cannulated screw of appropriate length is

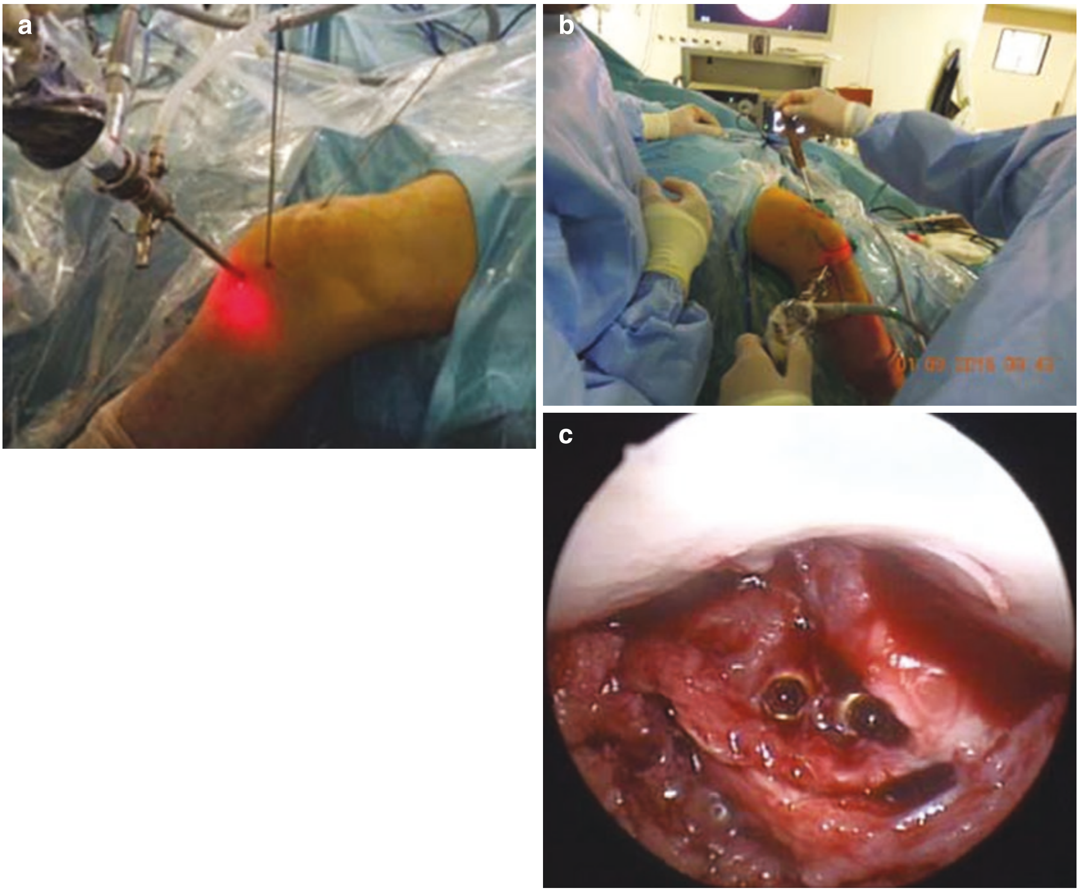

Fig. 30.1 (**a**, **b**) Creation of the “transquadricipital tendinous portal” and passing guidewire and cannulated screwdriver through this portal and (**c**) arthroscopic view from transquadricipital portal of the anatomic fixation with two cannulated screws

inserted into the fragment. Screw length, determined from preoperative radiography, should be long enough to make sure the threaded part passes the proximal tibial growth plate. During drilling and screw placement, a firm pressure should be applied onto the fracture fragment to maintain reduction as the screw is placed in the proximal tibial metaphysis. The screw head should be embedded within the ACL fibers to avoid contact with the articular cartilage surface. A second screw may be inserted in similar manner, if the fragment is of sufficient size.

During this step it is essential to obtain fracture consolidation and to perform an anterior drawer test under arthroscopic control to confirm no residual ACL laxity (Fig. 30.1c). Although Larsen et al. (2006) demonstrated that a drill hole diameter of ≥7% of the physis cross-sectional area can create a permanent bone growth disturbance, a recent review by Leeberg et al. (2014) identified only one reported bone growth disturbance due to transphyseal fixation. Accordingly, the evidence related to bone growth disturbance following transphyseal fixation is limited.

Thereafter, appropriate and proper anatomical position and tension of the ACL are checked arthroscopically. The knee is moved passively through full range of motion and checked for anterior impingement. In order to verify fracture fixation and ACL functional integrity, Lachman’s test is performed. There is limited need for fluoroscopic control. Postoperative radiograph of

Fig. 30.2 Postoperative lateral X-ray

fracture fixation is shown in Fig. 30.2. To prevent postoperative arthrofibrosis, an accelerated rehabilitation is advised (Parikh et al. 2014).

Twelve patients treated with this technique had excellent to good results without residual laxity or functional instability at a mean long-term follow-up of 49 months (Doral et al. 2001). Similar successful clinical results with the fixation through the patellofemoral joint space have been reported by Yung et al. (2013). The advantages of this technique are summarized in Table 30.3.

Table 30.3 Advantages of "transquadricipital tendinous arthroscopic approach" for the fixation of tibial eminentia fractures

• Avoids arthrotomy
• Good visualization of the lesion
• Easy reduction of the fracture by "perpendicularly oriented" guidewires
• Easy manipulation of the guidewires of the cannulated screws
• No risk of neurovascular injury
• Allows vertical rigid fixation in semi-flexed knee position
• Applicable to all arthroscopic fixation methods
• Good possibility to view additional intra-articular lesions
• Good visualization of the patellofemoral joint congruity
• No need for fluoroscopy
• Allows early motion, rehabilitation, and return to activity and sports

30.5 Conclusion

In conclusion, the healing rate is high after most nonsurgical and surgical approaches. Although residual anterior knee laxity may persist in the long term, the functional outcome is good in most patients. Among surgical methods, the "transquadricipital tendinous portal arthroscopic technique" provides several advantages for the fixation of displaced non-fragmented fractures. The most important advantages include rigid fixation of the fragment perpendicular to the fracture line and the avoidance of neurovascular injures.

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31

Knee Soft Tissue Injuries Combined with Tibial Plateau Fractures

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31.1 Introduction

In a patient who has sustained a tibial plateau fracture, damage to soft tissue structures of the knee is often present. The soft tissues at risk are the menisci, the cruciate and collateral ligaments, and, less frequently, the blood vessels and the nerves. Based on recent studies, these combined injuries occur frequently, especially after high-energy trauma (Stannard et al. 2010). As determined by arthroscopic evaluation, the reported incidence of knee soft tissue injuries in patients with tibial plateau fractures ranges from 50% to 71% (Abdel-Hamid et al. 2006; Fowble et al. 1993; van Glabbeek et al. 2002; Hung et al. 2003; Vangsness et al. 1994). The menisci and the anterior cruciate ligament (ACL) are most commonly involved (Asik et al. 2002; Chan et al. 2003, 2008; Chiu et al. 2013; Dall'oca et al. 2012; Di Caprio et al. 2010; Duan et al. 2008; Gill et al. 2001; Hung et al. 2003; Kayali et al. 2008; Kiefer et al. 2001; Levy et al. 2008; Ohdera et al. 2003; Pogliacomi et al. 2005; Roerdink et al. 2001; Rossi et al. 2008; Siegler et al. 2011; van Glabbeek et al. 2002), with overall incidence rates of 42.2% and 21.3%, respectively (Chen et al. 2015). Subsequently, it has been advocated that all tibial plateau fractures should be suspected for associated soft tissue injuries (Bennett and Browner 1994).

Damage to the menisci and/or ligaments of the knee, particularly if left undiagnosed and untreated, may contribute to the long-term morbidity and inferior outcomes that are often associated with tibial plateau fractures. Functional instability of the knee and residual laxity following tibial plateau fracture has long been recognized as a major cause of poor results. It remains unclear, though, whether the knee laxity derives from bony deformity or ligamentous insufficiency. Moreover, primary repair of injured menisci and/or ligaments accompanying tibial plateau fractures is still debated (Barrett et al. 2005). Nonetheless, in addition to appropriate tibial plateau fracture fixation, soft tissue stabilization of the knee may reduce residual laxity and improve functional recovery (Delamarter et al. 1990). In this respect, prompt diagnosis and proper management of soft tissue injuries in a knee with a tibial plateau fracture are of great significance in the acute setting.

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31.2 Imaging

Imaging is essential, not only for diagnosing and classifying fractures of the tibial plateau but also for securely evaluating the status of injured knee soft tissue structures. Knowledge of concomitant soft tissue damage prior to intervention is important, as it may affect the treatment plan and, perhaps, the ultimate outcome of this complex injury. To this effect, plain radiography, planar or computed tomography (CT), and magnetic resonance imaging (MRI) should be utilized in order to visualize or predict the details of the soft tissue injuries associated with tibial plateau fractures.

To assess fracture type and severity, tibial plateau fractures are typically evaluated using radiographs, conventional tomograms, or CT. As a matter of fact, CT has long been the preferred imaging method in most patients, to give detailed description and accurate classification of tibial plateau fractures (Dias et al. 1987; Rafii et al. 1984, 1987). However, soft tissue injuries are actually poorly detected using CT alone. In any case, radiographic images may provide significant and important information on possible damage to the menisci and/or ligaments of the knee in the presence of a tibial plateau fracture. It has been shown that knee soft tissue injuries occur more frequently with increasing displacement of the fractured tibial plateau. Hence, the degree of depression and/or widening of the tibial plateau has been proposed to be a predictor of concomitant soft tissue damage, based on the findings of a number of relevant studies that confirmed an association between the extent of bony displacement and the incidence of combined meniscal and/or ligamentous injuries (Durakbasa et al. 2013; Gardner et al. 2006; Mui et al. 2007; Ringus et al. 2010; Spiro et al. 2013; Wang et al. 2015).

MRI, on the other hand, is generally considered as the imaging modality of choice for depicting soft tissue injuries that accompany tibial plateau fractures (Barrow et al. 1994; Holt et al. 1995; Kode et al. 1994; Yacoubian et al. 2002). As determined by MRI, the incidence of meniscal and/or ligamentous injuries has been shown to be high in both displaced and minimally displaced tibial plateau fractures (Colletti et al. 1996; Gardner et al. 2005; Shepherd et al. 2002). Evidently, with the additional information given by MRI in terms of the condition of soft tissue structures of the knee with a tibial plateau fracture, the overall injury pattern can be better appreciated, thus facilitating decision-making and management planning.

31.3 Management

31.3.1 Meniscal Injuries

In the management of tibial plateau fractures, meniscal preservation is of great importance. The meniscus serves to protect the cartilage as well as providing stability to the fractured articular surface of the tibial plateau (Honkonen 1995; Scheerlinck et al. 1998). If at all possible, meniscal tears should be repaired after tibial plateau fracture fixation. Arthroscopic repair of the torn meniscus follows the conventional methods for meniscal suturing, where all-inside, outside-in, and inside-out techniques may be used (Chen et al. 2015; Ruiz-Ibán et al. 2012). Even when arthrotomy is performed, arthroscopy offers visualization and possible management of an injured contralateral meniscus. Injured menisci are trimmed, and partial or total meniscectomy is performed, only when suturing is not feasible.

31.3.2 Cruciate Ligament Injuries

ACL injuries are common in patients with tibial plateau fractures. Most ACL midsubstance tears are not operated on in the same setting as fracture fixation. Concomitant tibial plateau fracture fixation and ACL reconstruction have been described in earlier studies, but this considerably increases the complexity and duration of the operation (Jennings 1985). However, ACL bony avulsions (intercondylar eminence fractures) can be treated by arthroscopic-assisted fixation during the same operation as the tibial plateau fracture fixation (Chan et al. 2003, 2008; Chiu et al. 2013; Di Caprio et al. 2010; Rossi et al. 2008). Fixation can be performed using screws with a washer, nonabsorbable sutures, or a small steel wire. The sutures are threaded through the bone via a wire with an eye and are positioned on either side of the intercondylar eminence. Definitive fixation is achieved by knotting the distal suture legs on the anterior cortex (Burdin 2013). In case anterior knee instability exists after fracture healing, ACL reconstruction can be performed in a secondary setting. Posterior cruciate ligament (PCL) injuries are less common and are usually treated nonsurgically (Buchko and Johnson 1996; Scheerlinck et al. 1998).

31.3.3 Collateral Ligament Injuries

Severe damage to the collateral ligaments compromises coronal plane knee stability. To check for side-to-side instability, it is important that the knee is examined, if possible, before and after tibial plateau fracture fixation. MRI and, occasionally, stress radiographs may be useful in the preoperative evaluation. The majority of injuries to the collateral ligaments, especially those involving the medial collateral ligament, are treated nonsurgically. On the other hand, there are reports of posterolateral corner injuries in tibial plateau fractures, managed by ligament repair (Chiba et al. 2001; Conesa et al. 2013; Zelle et al. 2015). It has been suggested that lateral ligament complex injury may require immediate surgical treatment, especially in patients with the genu varum morphotype (Burdin 2013). Finally, chronic collateral instability can be managed in a secondary setting after fracture healing is complete.

31.4 Outcome

Studies reporting on the outcome of tibial plateau fractures with associated soft tissue injuries are quite sparse in the literature. As far as the management of meniscal damage in tibial plateau fractures is concerned, research evidence clearly favors repair over meniscectomy. Partial or total excision of an injured meniscus combined with a tibial plateau fracture has been shown to lead to poor functional outcome, with development of early osteoarthritis (OA) of the affected knee. It has been estimated that three out of four patients who have undergone meniscectomy at the time of tibial plateau fracture fixation develop secondary OA (Honkonen 1995). By comparison, meniscal repair has been associated with significantly better outcomes. It has been suggested that acute repair of a torn meniscus in the presence of a tibial plateau fracture can produce functional results similar to cases without meniscal injury (Forman et al. 2013). Clinical outcomes of meniscal repair have been found to be good to excellent, with a high healing rate, as evidenced by second-look arthroscopy (Ruiz-Ibán et al. 2012). Repair of damaged collateral ligaments of the knee, at the same time as tibial plateau fracture fixation, has also been proposed to avoid residual laxity that may lead to inferior functional outcomes (Delamarter et al. 1990).

31.5 Conclusion

Tibial plateau fractures are frequently accompanied with damage to soft tissue structures of the knee, including the menisci and the cruciate and collateral ligaments. Failure to take into account these concomitant injuries in dealing with tibial plateau fractures may lead to residual knee laxity and, ultimately, to poor outcomes. Therefore, early identification of meniscal and/or ligamentous damage associated with a tibial plateau fracture by proper imaging techniques is of great importance, allowing for better appreciation of the overall injury and optimal treatment planning. In these complex cases, reduction and internal fixation of the fractured tibial plateau as well as repair of injured menisci and/or ligaments can be performed by means of arthroscopic-assisted surgery. The use of arthroscopy has proven to be a safe, reliable, and effective strategy for the management of tibial plateau fractures with concurrent soft tissue injuries.

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Arthroscope-Assisted Surgical Treatment of Patellar Fractures

32

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Patella fractures constitute approximately 1% of all skeletal injuries (Court-Brown and Caesar 2006). Most of the fractures are transverse and involve the middle third of the patella. Since patellar fracture is intra-articular, the main treatment goal is restoration of the articular surface making it congruent and stable (Muller et al. 1979). Displacement of the fragments or articular step-off more than 2 mm is a widely accepted indication for surgical treatment. The extensor mechanism is disrupted in displaced transverse fractures of the patella. Open reduction and internal fixation using screws or (K)-wires along with cerclage wire (Zuggurtung tension band wiring technique) has remained the gold standard in surgical treatment (Harris 2001). Wire breakage or migration can result in prominent and painful hardware around the knee joint. Some authors have modified the technique with cannulated screws instead of K-wires due to the problem of K-wire migration and subsequent reduction loss (Appel and Seigel 1993; Chiang et al. 2011; El-Sayed and Ragab 2009; Tandogan et al. 2002). The accompanying soft tissue problems which have frequently been encountered have led knee surgeons to explore less invasive methods. Some minimally invasive techniques use fluoroscopy to confirm patellar fracture reduction; however, arthroscopic assistance may be particularly helpful in many patients (Chiang et al. 2011; El-Sayed and Ragab 2009; Mao et al. 2012, 2013; Tandogan et al. 2002).

The patella plays a crucial role in the knee extensor mechanism. In many patients, open reduction and internal fixation techniques, visualization of the entire joint surface and the entire fracture line, may be difficult. In most of these patients visualization and reduction efficacy is monitored by palpation from the inside of the patellofemoral joint as neither inspection nor fluoroscope may be adequate to detect a minor articular surface step-off (Maeno et al. 2013). Failure to obtain precise data with regard to reduction quality may mislead the surgeon resulting in a less favourable result. This is the main reason why arthroscopy is useful to assist with patella fracture management. Some surgeons have also reported that arthroscope-assisted percutaneous patellar fracture stabilization may overcome surgical delays associated with the presence of concurrent soft tissue lesions such as skin lacerations or abrasions (Luna-Pizarro et al. 2006; Turgut et al. 2001).

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32.1 Surgical Technique

The patient with a comminuted patellar fracture with a vertical and transverse component (Figs. 32.1 and 32.2) is placed supine on the operating table under general, spinal, or regional anaesthesia.

A standard knee arthroscopy set-up is prepared; the arthroscopy tower and the fluoroscope are positioned across the operating table. The scope is introduced through the suprapatellar portal (Fig. 32.3).

This is followed by joint lavage and removal of loose bodies, chondral flaps, and haematoma debris through the trocar. The second portal is placed just close to the distal pole of the patella. The fracture line is carefully evaluated (Fig. 32.4).

Fracture fragment reduction is achieved with the help of two Weber clamps (AR-8943S), one clamp placed transversely and one placed vertically with the knee in extension (Fig. 32.5).

Fracture reduction may be verified under image intensifier control if necessary. Then, the

Fig. 32.1 Preoperative radiographs of a patient with transverse and vertical fracture line

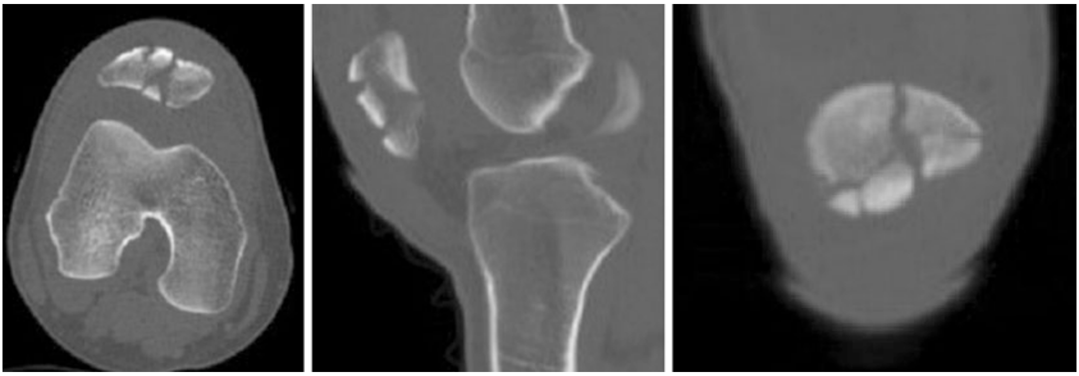

Fig. 32.2 Preoperative axial, sagittal, and coronary CT views

Fig. 32.3 Arthroscopy and fluoroscopy set-up

quality of fracture reduction is arthroscopically confirmed (Fig. 32.6a–c).

After verifying that the fracture line step-off is less than 2 mm, the knee is flexed to 15–20° to facilitate K-wire placement. With the help of a clamp, the soft tissues are released to provide the easy passage of the cerclage wire (Fig. 32.7).

Two 1.6 and 2.0 mm diameter K-wires are placed vertical to the transverse fracture line through the distal portal. The implant options may include K-wires or cannulated screws which are implanted over the K-wires. An “8 configuration” is made of the cerclage wire, and it is placed through the distal portal and pushed forward subcutaneously until it reaches the proximal end of

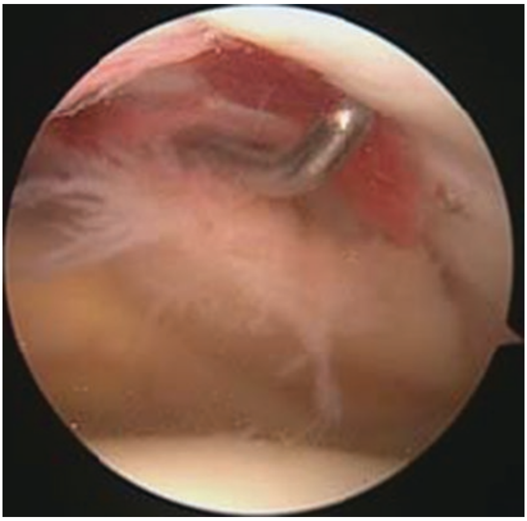

Fig. 32.4 The fracture line is evaluated with the probe

Fig. 32.5 Reduction is achieved with the help of two Weber clamps

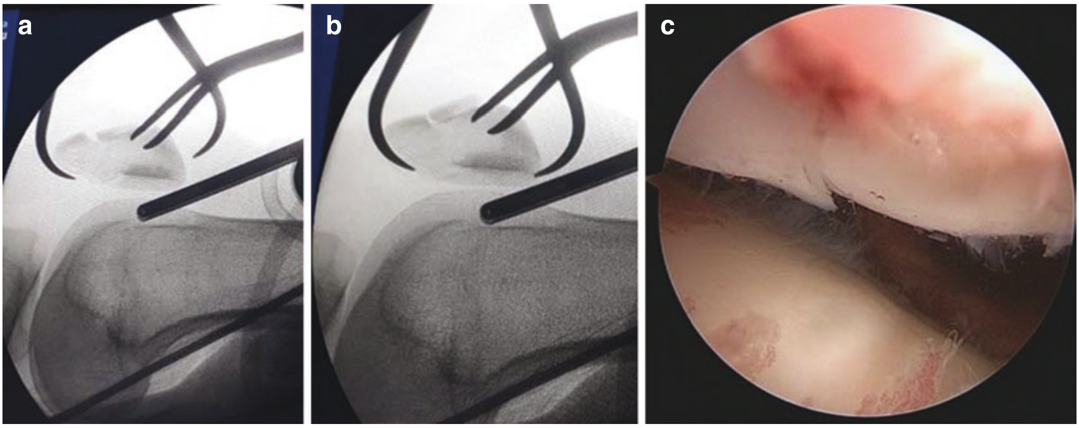

Fig. 32.6 (**a**, **b**) Fluoroscopic views before and after the reduction. (**c**) Arthroscopic view of the reduction

the K-wires. Then the free ends of the loop are tied into a knot at the distal portal (Figs. 32.8, 32.9, and 32.10).

In patients, where cannulated screws are used for fixation, the cerclage wire is passed through the distal end of the first screw and pulled out of the proximal end of the screw. Partial weight-bearing on two crutches is allowed for 3 weeks. Full weight-bearing is allowed during the 6th week post-surgery with radiographic evidence of fracture healing. Quadriceps strengthening exercises are started after the sixth post-operative week. An alternative approach may be arthroscope-assisted open reduction and internal fixation. After the standard arthroscopic set-up with anterolateral and anteromedial portals, a midline longitudinal incision is made, and fracture fragment reduction is achieved with the help of Weber clamps or towel clips with the knee in

Fig. 32.7 The soft tissue release through the distal portal with a clamp

Fig. 32.8 The arthroscopic portals

Fig. 32.9 Post-operative radiographs of the patient

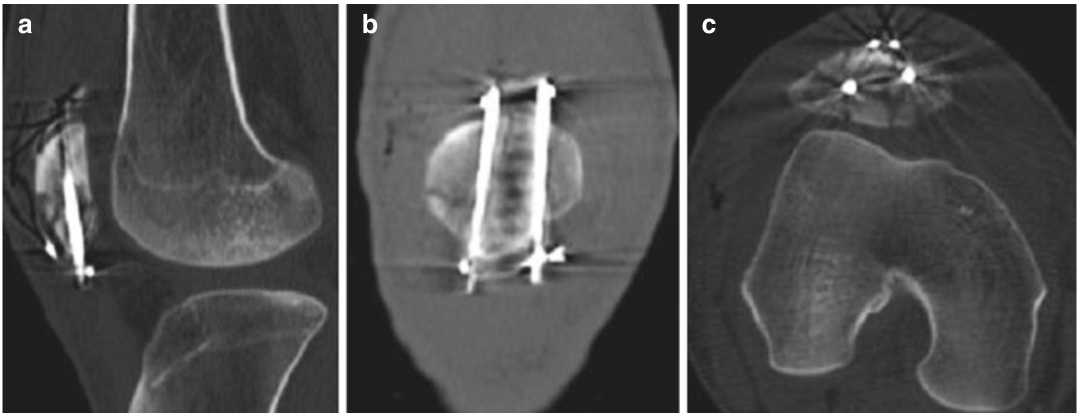

Fig. 32.10 (**a–c**) Post-operative sagittal, coronary, and axial CT images

extension. Then, the quality of fracture reduction is arthroscopically confirmed. After verifying that the fracture line is reduced, the knee is flexed to 15–20° to facilitate K-wire placement. Two K-wires (1.6–2.0 mm) are placed vertical to the transverse fracture line.

32.2 Discussion

Problems encountered with conventional surgical methods have resulted in a trend towards percutaneous methods. A new minimally invasive compressive, external fixation technique has been described where fracture reduction quality is confirmed either using fluoroscope control or by palpation (Wardak et al. 2012). A percutaneous tension band wiring technique is used to pass a cerclage wire through portals placed at each corner of the patella. Following this, fracture reduction is checked using fluoroscopy (Makino et al. 2002; Rathi et al. 2012). Using a novel, minimally invasive technique in which partially threaded cannulated screws and a braided wire ("cable pin system") and fluoroscope confirm reduction, Mao et al. (2012) have reported good results in a study of 31 patients with displaced patella fractures. They reported that although operative time was increased for the minimally invasive treatment group, functional results were better with less post-operative knee pain and faster recovery of knee range of motion, higher Böstman scores, and fewer complications compared with an open tension band wiring technique (Mao et al. 2012, 2013).

A percutaneous technique has been described where two Steinmann pins were placed transversely in the quadriceps and patellar tendons through incisions placed near the superolateral and inferior corners of the patella. As Steinmann pins were used to aid fracture reduction, K-wires and a cerclage wire were placed percutaneously. Patellar fracture reduction was then verified with a clamp through the superolateral incision. In a randomized controlled trial, comparing the results of 27 patients who underwent percutaneous technique with 26 patients who underwent an open technique, Luna-Pizarro et al. (2006) reported shorter surgical time, reduced knee pain at the fourth and eighth post-operative weeks, and better knee function at the eighth post-operative week and at 1 year post-surgery in the percutaneously treated group.

In the presence of concurrent retinacular tears, an open technique is preferred since sole use of percutaneous and arthroscopic methods is an not sufficient to repair the retinacular injury (Tandogan et al. 2002). Melvin and Mehta (2011) have stated that it is essential to meticulously select patients who might benefit from arthroscopic treatment approach. Tandogan et al. (2002) reported that in cases where patella fracture reduction stability cannot be achieved with screws alone, an arthroscopic-assisted technique using partially threaded cannulated 4 mm screws and a cerclage wire for additional fixation can be effective. Turgut et al. (2001) described an arthroscopic-assisted percutaneous technique when treating patients with concurrent superficial abrasions and local contusions where a circumferential cerclage wire loop is placed around two Kirschner wires crossing each other.

Maeno et al. (2013) described a novel arthroscopic technique to enable both extra-articular and intra-articular patellar views. This technique used a “semi-loop” hanger under dry arthroscopy during the extra-articular approach (Maeno et al. 2013). Comminuted patellar fractures remain a challenge for knee surgeons. In treating four patients with five comminuted patellar fractures, Yanmis et al. (2006) reported good results following fracture fragment reduction under arthroscopic visualization and application of a circumferential external fixator at a mean 22-months post-surgery (range 20–28 months). Arthroscopic treatment of patella fractures allows for knee joint lavage including washing out of haemarthrosis, small bone fragment, or chondral flap removal without the need for arthrotomy. Achieving effective fracture reduction and stabilization using a closed method that incorporates joint lavage may decrease post-operative knee adhesions substantially. Less invasive techniques are known to better preserve fracture fragment vascularity, may enhance fracture healing, and better improve patient function. First and foremost, patella fracture reduction verification is more accurate with arthroscopic techniques. Patients with an intact patellar retinaculum are ideal for arthroscopic-assisted patella fracture fixation. With comminuted or displaced patella fractures, the probability of having an associated retinacular tear is higher. Even in these patients, the arthroscope may still be of use for evaluating fracture fragment reduction, particularly at the joint surface.

32.3 Conclusion

In conventional patellar fracture surgery, after fracture reduction is performed, the quality of reduction is evaluated by palpation. This may result in unfavourable outcomes. As with all intra-articular fractures, arthroscopy provides accurate information regarding the quality of reduction in patellar fractures. The whole surgical procedure can be done arthroscopically through two portals, or arthroscopy may be used as an aid in evaluating the reduction with a standard midline incision.

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33

Patella Fractures by Different Techniques

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33.1 Introduction

Patellar fracture is a common injury representing around 1% of all fractures in adults (Weber et al. 1980). Several fracture patterns have been described, including vertical (at the central one/third) and horizontal (at the superior or inferior pole or central), with or without fragment displacement, asteroid, and osteochondral. One accepted classification is the one described by Duparc et al., which takes into account the mechanism of trauma and the presence of articular surface impaction (Ricard and Moulay 1975). Type I fractures occur after a pure knee flexion with a violent quadriceps muscle contraction episode. They are simple transverse fracture at the junction between the two, more proximal thirds and the distal third, with no impaction or displacement. Type II fractures include transverse fracture with a comminuted or impacted distal fragment. They follow a sagittal compression of the distal patellar pole with the trauma compressing the patella against the femoral condyles with an impaction. Type III fractures include severely comminuted patella fragments after anterior-posterior compression such as direct trauma against a car dashboard.

Most of these knee fractures have a transverse pattern and involve the middle third of the patella in patients aged 20–50 years (Ashby et al. 1975), affecting almost twice as many men as women (Hung et al. 1985). Non-displaced fractures can be treated conservatively with satisfactory results. However, prolonged immobilization is associated with arthrofibrosis and stiff knee (Muller et al. 1979). In cases of patella fragments displacement and articular incongruence, surgery must be considered. In fact, articular incongruity is the leading cause of post-traumatic arthritis of the patellofemoral joint (Marsh et al. 2002). Open reduction and internal fixation is still the standard of care and is often associated with good and excellent outcomes (Harris 2001). The goal of this approach is to obtain an anatomical articular surface reduction and allow early mobilization through a stable fixation. Several internal fixation techniques have been described, including cerclage wiring, tension band wiring with or without transfixing screws, external fixation, and percutaneous suture fixation (Benjamin et al. 1987; Carpenter et al. 1997; Marya et al. 1987; May et al. 1984; Neyret 1995; Weppe et al. 2014). However, all these techniques are associated

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with general and specific complications related to the use of an open approach, fixation device, or both. They include infection (up to 14%) (Gosal et al. 2001), delayed wound healing (up to 8%) (Hung et al. 1985), partial patellar necrosis from blood damage, and peripheral nerve disturbances especially of the saphenous nerve branches (Muller et al. 1979), broken wires (up to 25%) (Hung et al. 1985) (Fig. 33.1), irritation from the devices (up to 43%) (Perry et al. 1988) (Fig. 33.2), and migration of Kirschner (K) wires and hardware or fixation failure (up to 7%) (Gosal et al. 2001) with reported revision rates varying from 7% to 43% (Gosal et al. 2001; Hung et al. 1985; Perry et al. 1988; Us and Kinik 1996; Wu et al. 2001).

In addition, although stable fixation and anatomical reduction are achieved at the time of surgery, late loss of reduction, fragment displacement, articular step-off, and cartilage loss have been reported (Marsh et al. 2002). Minimally invasive or percutaneous osteosynthesis for displaced fractures of the patella offers several advantages compared with traditional open surgery. They include shorter surgical time, better knee mobility, higher functional score, and lower complication rates (Luna-Pizarro et al. 2006). Unfortunately, despite this wide spectrum of advantages, some concerns exist in terms of fracture reduction quality. When closed reduction is attempted with the aid of fluo-

Fig. 33.1 Broken K-wires are one of the most common complications

Fig. 33.2 Bulky metallic fixation devices may cause soft tissue irritation

roscopy alone, great care should be taken to correct rotational fragment displacement. In fact, the precise shape of the patella can be hardly reconstructed using a two-dimensional monitor. Additionally, since skyline and anterior-posterior views may be confusing, the lateral view alone is used as a reliable intraoperative tool. The association of fluoroscopy and arthroscopy is advantageous in achieving anatomic reduction. To date there are few reports on arthroscopically assisted patellar fixation techniques (Turgut et al. 2001; Makino et al. 2002; Tandogan et al. 2002; Yanmis et al. 2006; El-Sayed and Ragab 2009; Chiang et al. 2011a, b). Nonetheless, the advent of arthroscopy has offered several advantages including the decompression of intra-articular hematomas, the removal or debridement of loose fragments, and the possibility of treating articular cartilage lesions. Additionally, arthroscopy allows precise visualization of the articular surface of isolated osteochondral fractures or impaction (Kanamiya et al. 2006) and reduction assessment.

33.2 Analysis of the Literature

Sattler and Schikorski (1987) were the first to describe the advantages of an arthroscopically assisted technique of reduction and percutaneous fixation in case of displaced transverse patellar fractures. Following this study, other surgeons reported their variations to this original technique, including simple screw fixation, tension band with K-wires, and screw fixation in association with tension band technique.

33.3 Screw Fixation

Appel and Seigel (1993) described for the first time an arthroscopically assisted screw fixation technique (Fig. 33.3) for transverse patellar fractures (Fig. 33.4).

Fig. 33.3 Screw fixation is one of the most common options for the treatment of transverse patellar fractures

With the patient supine and the knee in extension, a preliminary arthroscopic examination allowed precise joint visualization with no need for extensive dissection to provide fracture or joint surface visualization. The fracture was then reduced under fluoroscopic and arthroscopic assistance with two towel clips. Two longitudinal parallel K-wires were inserted, as guides for two compression screws. Although the authors did not report results from any patient case series, they stressed the advantages of this new technique over the traditional open surgery: less disability and discomfort, substantially shorter hospitalization, and accelerated recovery.

El-Sayed and Ragab (2009) reported on arthroscopically assisted closed reduction and percutaneous screw fixation, in a series of 14 patients affected by transverse patellar fractures. After the fracture was percutaneously reduced with a clamp and under fluoroscopic assistance, arthroscopy was performed. Once the hemarthrosis was washed out, the integrity of the articular cartilage layer and the extent of the reduction were assessed. The fracture was then secured with two K-wires, which were positioned perpendicular to the fracture both medially and laterally, and then fixation was achieved using two partially threaded 4.0 mm compression screws. The compression and stability of the construct was monitored under arthroscopy while flexing and extending the knee. At an average follow-up of 26 months, the average Lysholm score was 93, and the majority of patients regained pre-injury range of motion.

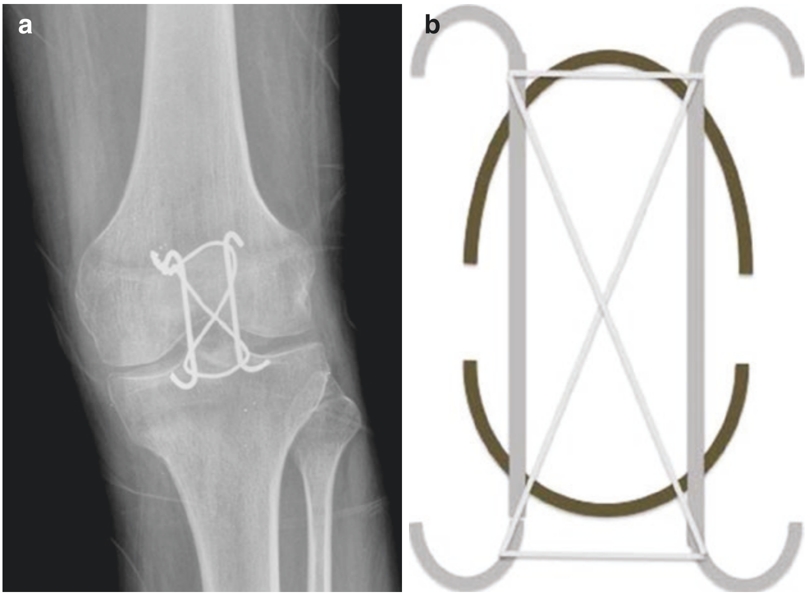
Fig. 33.4 Transverse patellar fractures represent the ideal indication for arthroscopically assisted fixation techniques

33.4 Cerclage and Tension Band Wiring Technique

Turgut et al. (2001) reported the outcomes of percutaneous, arthroscopically assisted osteosynthesis of displaced patellar fractures in a series of 11 patients (Fig. 33.5a, b).

With patients in supine position and the knee in full extension, an inferolateral portal was established to evacuate the hemarthrosis. Once the reduction was carried out with manipulation using percutaneous towel clips, and assessed under arthroscopic and fluoroscopic control, three stab incisions were made at the superolateral, superomedial, and inferomedial corners of the patella. Two K-wires were positioned from superolateral to inferomedial and from superomedial to inferolateral incisions. A metallic wire was then inserted from the superolateral incision and advanced medially with the aid of a straight needle. Once it was retrieved from the superomedial incision, the procedure was repeated for the inferomedial, inferolateral, and then again for the superolateral incisions. The two free ends were

Fig. 33.5 (**a**, **b**) Tension band over K-wires technique is widely adopted in association with minimally invasive approaches



twisted several times under arthroscopic and fluoroscopic control. Finally the remaining ends of the cerclage and K-wires were resected, and the stump of the cerclage was buried in the subcutaneous tissue. At an average follow-up of 2.8 years, all fractures healed without complications, and good results were obtained in all patients.

33.5 Screws and Tension Band

This surgical option has been widely adopted with open techniques in the past (Fig. 33.6).

Biomechanical analysis of cadaver knees showed the efficacy of figure-of-eight tension band over a two-screw technique (Carpenter et al. 1994). In fact, it provided the most rigid fixation and resistance to construct failure compared with screws alone and a modified tension band technique.

Fig. 33.6 Tension band in association over screws is a reliable option in association with both open and arthroscopic techniques

Makino et al. (2002) described his technique of arthroscopic-assisted reduction of transverse patellar fractures in a series of five patients. The procedure was performed with the patient in the supine position and the knee in full extension. The fracture was reduced under fluoroscopic control and with direct visualization of articular congruence of the fragments through the common anteromedial and anterolateral portals. Two parallel K-wires were placed perpendicular to the fracture as guide wires for two cannulated 3.5 mm compression screws. Interfragmentary compression was assessed under direct intra-articular visualization of the articular surface. An additional cerclage was performed with two 1.25 mm metallic wires. They were both inserted through the cannulated screws and then crossed under the skin and superficial to the patella to obtain a figure-of-eight pattern tension band. At an average follow-up of 18 months, all five patients had regained a normal range of motion and returned to their pre-injury activity level.

Tandogan et al. (2002) described a similar technique in a series of five patients with displaced patellar fractures. The procedure was carried out in full extension, and arthroscopy was performed through the standard anteromedial and anterolateral portals. A superolateral portal (1–2 cm superolateral to the superolateral corner of the patella) was created to assist the percutaneous reduction of the fragments with the aid of an intra-articular probe. Two 18 gauge needles were placed under arthroscopic control, proximal to the superior patellar pole, as a reference for further K-wire positioning. The direction of the needles and later of the K-wires was perpendicular to the fracture and at least 2 cm apart. K-wires were positioned once the needles had been withdrawn so they could be used like “joysticks” to manipulate the fragments as needed. After fluoroscopic and intra-articular assessment of the reduction, fixation was achieved with partially threaded cannulated 4 mm screws inserted over the wires. The length of the wires was calculated and adjusted under fluoroscopic control. The stability of the final fixation was assessed by flexing and extending the knee under arthroscopic control (with the superolateral portal used as the viewing portal). If fixation stability was judged to be inadequate, additional circular cerclage was applied using two additional stab wounds at screws ends. A stainless steel wire was passed from proximal to distal through the first screw, retrieved subcutaneously at the distal end of the second screw, and passed from distal to proximal. At this level it was then possible to tie the two free ends under tension. At an average follow-up of 29.6 months, the average Lysholm score was 84.8, and no signs of arthritis were reported.

Chiang et al. (2011a) reported the outcomes of modified Carpenter's technique in a series of 21 patients with displaced transverse patellar fractures. After arthroscopic intraoperative debridement and hematoma removal, the fracture was percutaneously reduced with a clamp with the knee in full extension. The extent of any displacement was assessed under fluoroscopic control, whereas intra-articular congruity was confirmed using arthroscopy. The knee was then flexed at 15° to facilitate guide wires insertion. Two parallel K-wires were inserted medially and laterally from the superior patellar pole to reach the skin at the inferior pole (using four stab incisions). Once the presence of 1.5–2 cm bony bridges between the wires was confirmed under fluoroscopy, two 4.0 mm partially threaded compression screws were inserted from the proximal pole. The screws were 4–5 mm shorter than the measured length in order to avoid lower patellar pole penetration once the fracture was impacted. After clamp removal, the first 1.2 mm K-wire (30 cm long) was passed antegrade through the first cannulated screw to emerge 1.5 cm distally to the distal incision. A cannula was then passed from the proximal incision of the second screw to the distal incision of the first screw. Once the K-wire was bent distally and retrieved proximally through the cannula, the same procedure was carried out on the second screw. In this way at the level of the superior screw tip and K-wire, couples were carefully controlled. The K-wires ends were then twisted to reach the screw tip tightening the cerclages. Fracture reduction and cerclage tensioning were evaluated at up to 90° of knee flexion under fluoroscopic control. At last follow-up (38.8 months after surgery), average knee flexion was 140.8° (range 135–150°), and the average Lysholm score was 93.9 (range 86–100). The functional outcomes of the modified Carpenter's technique (Carpenter et al. 1994) were superior to those obtained with standard open modified anterior tension band technique with lower incidence of complications and reoperations (Chiang et al. 2011b).

Three other studies described different surgical options: the first reported a combined intra- and extra-articular arthroscopic fixation technique, the second a fixation technique of osteochondral fractures, and the last a novel technique to treat comminuted patellar fractures by circular external fixator under arthroscopic control. Maeno et al. (2013) described a technique of intra- and extra-articular knee arthroscopy. The first step was an arthroscopic approach to wash out the hemarthrosis and to assess the status of the articular cartilage. A subcutaneous working space extending to the medial and lateral pouches was then established. The dissection was carried out to achieve a sufficient extra-articular working space, and then a lifting hanger was applied to the anterolateral (AL) portal to perform a dry arthroscopy. The soft tissues and hematoma were removed to expose the fractured patella edges under arthroscopic control (the arthroscope was inserted through the AL portal). Under direct visualization the fracture was reduced and fixed with two K-wires. The wires were then inserted both medially and laterally through additional 1-cm-long superolateral and superomedial incisions and could be used for temporary fixation or to act as guide pins (1.6 mm) for placing screws. In addition they could be part of a tension band fixation (2.0 mm), which were positioned through these four small incisions.

Tonin et al. (2001) were the first to describe an arthroscopic technique of fixation of osteochondral fractures of the patellar ridge in patients with loose medial retinaculum as a consequence of previous patellar dislocation. The procedure was performed with patients in the supine position with the knee flexed to 90°. Once the two standard arthroscopic portals were established, the joint was washed from the hematoma. The exposition of the patellar ridge was achieved extending the knee, pushing the patella medially, and tilting it laterally. Whenever the exposition of the ridge was difficult or not possible, a threaded wire was drilled transversely from the medial side into the patella and used like a "joystick" or lever to mobilize it. The location of the osteochondral fragment was debrided through the anteromedial portal, and the fragment was reduced with the aid of a probe. A superior anteromedial portal was established as a working portal, and a cannula was positioned. A threaded wire was inserted through the cannula to temporarily fix the fragment. Once satisfactory reduction was obtained, three or more channels were drilled perpendicularly through the fragment into the receiving bed using a 1.3 mm K-wire. Absorbable rods were introduced into the channels and cut to the desired length. Fixation of the fragment could alternatively be achieved using cannulated screws or staples.

Yanmis et al. (2006) described a technique of reduction and arthroscopically assisted external fixation in comminuted fractures. Comminuted fractures cannot be treated with internal fixation as effectively as displaced transverse fractures. The proposed technique represents an alternative to the traditional partial or total patellectomy. After the traditional anterolateral viewing portal was established, the joint was washed, and the integrity as well as the congruence of the patellar fracture was assessed. Fixation was achieved using either the 5/8 standard rings or 20 full ring and 4 mm K-wires. When reduction was necessary, it was performed percutaneously with one or more towel clamps. When the reduction was not needed, a preliminary transverse wire was positioned into the proximal fragment and fixed to the ring. Additional K-wires were then inserted crosswise one by one to be compressed and then stretched before being fixed to the ring. The outcomes of this technique were reported in a series of five patients. At an average follow-up of 22 months, the average Lysholm score was 94, and no local or general complications were reported.

33.6 Conclusion

The treatment of articular fractures necessitates appropriate preoperative evaluation as well as precise surgical technique to guarantee good functional outcomes and avoid early and late complications. Problems may include reduced range of motion and articular surfaces incongruence with late articular cartilage degeneration and finally osteoarthritis. These problems are an important social cost and common cause of reduced quality of life. The necessity of perfect fragment reduction is crucial. When dealing with patellar fractures, intraoperative fluoroscopy evaluation is sometimes not able to adequately assess the quality of fragment reduction and fixation. Arthroscopy has been introduced to reduce the damage of vascular supply of the patella and to assess articular cartilage status before surgery and to confirm the quality of reduction and the stability of fixation. Additionally, reduced soft tissue damage allows for early postoperative range of motion exercises and faster functional recovery. Nonetheless it is a technically demanding procedure, with limited indications.

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34

Articular Cartilage Injuries Associated with Patellar Dislocation

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Efthymios Iliopoulos, and Dimitrios Metaxiotis

34.1 Introduction/Epidemiology

Patellar dislocation prevalence is approximately 7/100,000 individuals in all age groups, with a peak in adolescence (107/100,000) (Atkin et al. 2000; Nietosvaara et al. 1994). It has been estimated that 43/100,000 children younger than 16 years of age have an episode of acute patellar dislocation. Recurrent subluxation is more common in girls than in boys. Younger children (<14 years) are more likely than older children to develop recurrent dislocations (Stefancin and Parker 2007). Chondral and osteochondral lesions after patellar dislocation are relatively common in athletes (Nomura and Inoue 2004, 2005).

Osteochondral or chondral injuries have been reported in up to 95% of acute dislocations (Nomura and Inoue 2004). Loose bodies visible on imaging are commonly regarded as an indication for early surgical treatment (Stefancin and Parker 2007). The high incidence of osteochondral as opposed to chondral fractures in this generally young age group may be due to age-related properties of the subchondral bone, calcified cartilage, and cartilage layers (Buckwalter 2002).

Patellofemoral joint articular cartilage is subjected to both compression and shear forces. These forces can lead to instability of the chondral lesions. Patellofemoral contact pressure reaches its highest level (12Mpa) between 60 and 90 degrees of knee flexion. The severity of the articular cartilage lesion, however, depends on the type of the patellar dislocation (acute or recurrent), the underlying bony morphology, and the force (a high- or low-energy knee trauma). In other words, the associated articular cartilage lesions to a certain extent depend on the patient's anatomy or pathoanatomy. This in turn means that the mechanical force magnitude needed to cause a dislocation is inversely proportional to the amount of patellofemoral dysplasia. Thus, a dysplastic trochlea will allow a dislocation at lower energy levels than normal morphology would allow, and its associated chondral lesion in the acute setting will often be minimal compared with what happens in the presence of normal knee morphology. In terms of recurrent dislocations or in the presence of patellar instability in general, additional articular cartilage damage may occur, eventually progressing to osteoarthritis. In acute dislocations, macroscopic signs of

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articular cartilage lesions include fissuring and chondral or osteochondral fractures (Lording et al. 2014).

The most common location is at the medial facet and/or inferomedial pole of the patella and the lateral femoral condyle (kissing lesion). The main origin of loose bodies is from the patella and/or the femur. Loose bodies are common in as many as 31–58% of these cases and require special management especially in younger ages (Elias et al. 2002; Seeley et al. 2013; Stanitski and Paletta 1998). In recurrent patellar dislocation, the articular cartilage lesions include fissuring (central dome) and fibrillation and/or erosion, which are frequently observed at the medial facet (Farr et al. 2012). When treatment is planned, it is important to consider not only to correct the patellar instability but also to treat the articular cartilage lesion. In the past, many procedures showed excellent results in terms of correcting patellar instability, causing, at the same time, rapid chondral erosion, with development of osteoarthritis in the medium term (Barbari et al. 1990; Crosby and Insall 1976).

34.2 Imaging

The information provided by plain knee radiographs is focused mainly on predisposing factors of patellar instability. Unfortunately, 40% of osteochondral defects are not visible in plain radiographs. Standard radiographic assessment includes anteroposterior and lateral knee radiographs performed, if possible, in a weight-bearing position. Knee deformities (genu varum, valgum, or recurvatum) are evaluated. These images are effective to detect concomitant fractures (tibial plateau, patella, Segond fracture), anatomic variations (bipartite patella), patellar position abnormalities (patella alta or baja), or loose bodies (usually in the lateral gutter). The depth/dysplasia of the trochlea can be estimated using the sulcus line on straight lateral radiographs (crossing sign, double contour sign, supratrochlear spur) and axial views (Krause et al. 2013).

Computed tomography (CT) provides assessment of the distance between the tibial tubercle and trochlear groove (TT-TG), and when combined with arthrography, it can assist in detecting chondral lesions and loose bodies (Earhart et al. 2013). Magnetic resonance imaging (MRI) is considered the gold standard to detect cartilage and subchondral lesions and thereby assisting in management planning (Fig. 34.1) (von Engelhardt et al. 2010). Although patellar articular cartilage is thick and can be examined in both axial and sagittal views, the best diagnostic evaluation is achieved using axial views. On the contrary, the cartilage of the trochlea is technically more demanding due to less thickness compared with the patella and the complex morphology. Therefore, better visualization is achieved in sagittal rather than axial views. Fat-suppressed 3D spoiled or T1-weighted gradient-echo and fat-suppressed echo techniques have better accuracy (Earhart et al. 2013).

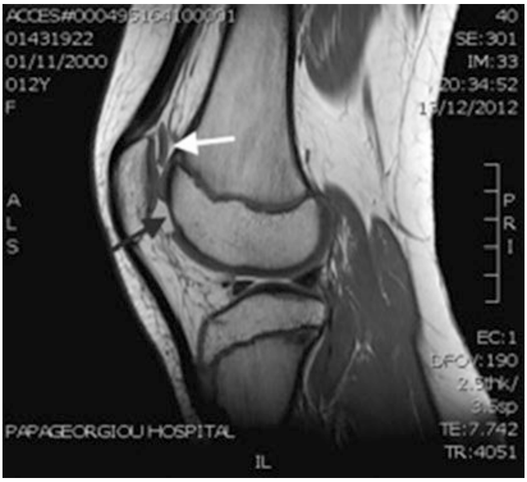

Fig. 34.1 MRI scan (sagittal view) 3 months after patellar dislocation. A large chondral fragment is in the suprapatellar space (white arrow). The fragment comes from the lateral femoral condyle (black arrow)

34.3 Management

The management of articular cartilage lesions associated with patellar instability varies extensively, depending on lesion size, osteochondral fragment integrity, and the time from injury. It is of major importance to be aware of these lesions after patellar dislocation and evaluate the patient's history, findings of physical examination, and imaging studies in order to select the best treatment option.

As previously mentioned, this injury more frequently involves the medial facet and/or inferomedial patellar pole and the lateral femoral condyle (Fig. 34.2). After acute traumatic patellar dislocation, the size of the fragments ranges from small comminuted pieces to large osteochondral fragments, sometimes involving a considerable part of a condyle. Early surgical intervention is indicated in such cases to treat the articular cartilage injury properly (Farr et al. 2012; Lording et al. 2014).

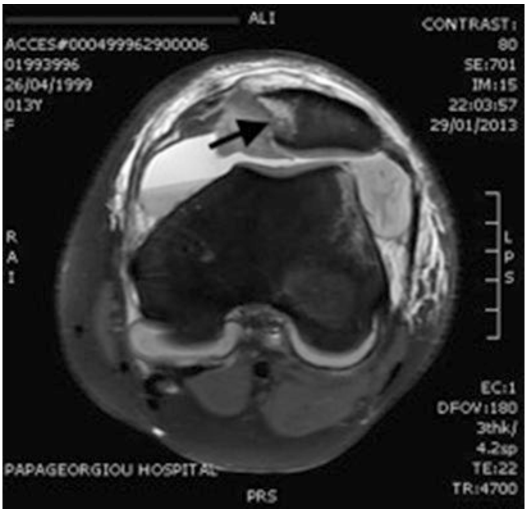

Fig. 34.2 MRI scan (axial view) after traumatic patellar dislocation. There is a large osteochondral lesion affecting a large part of the medial facet of the patella (arrow)

Comminuted loose fragments often need to be removed to clean the joint. If possible, one or more of the larger intact fragments should be fixed in the site of the lesion. The surgeon should attempt this even if full congruity between the articular cartilage fragment and the lesion site cannot be achieved. In this case, the chondral fragment is formed appropriately to fill the lesion site as good as possible. Current best practice for fixation is interfragmentary compression using bioabsorbable or nonabsorbable cannulated screws (which may need to be removed) or bioabsorbable pins (Gkiokas et al. 2012; Kumahashi et al. 2014; Lee et al. 2013) (Figs. 34.3 and 34.4).

When an acute cartilage lesion is missed or chronic lesions are present related to recurrent episodes of patellar dislocation, initial treatment involves a nonsurgical approach, and surgery is reserved for patients with persistent symptoms or loose bodies. In these cases, the articular cartilage procedures are always reconstructive and should be combined with management of patellar instability. For successful articular cartilage repair, it is important to address any underlying lesion. Thus, medial patellofemoral ligament

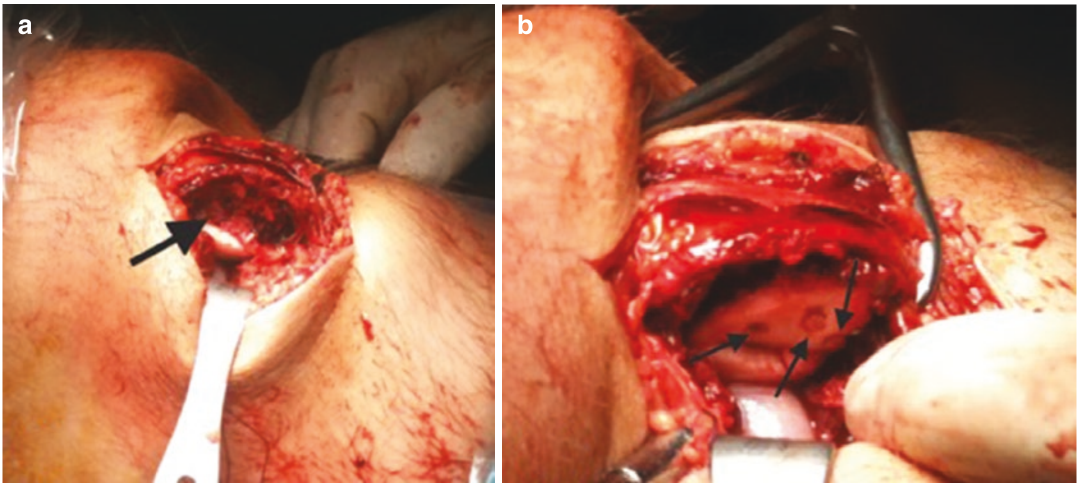

Fig. 34.3 Intraoperative image of patella's medial facet osteochondral lesion after traumatic dislocation, before (**a**, arrow) and after (**b**) the fixation of the fragment using three bioabsorbable pins (three arrows)

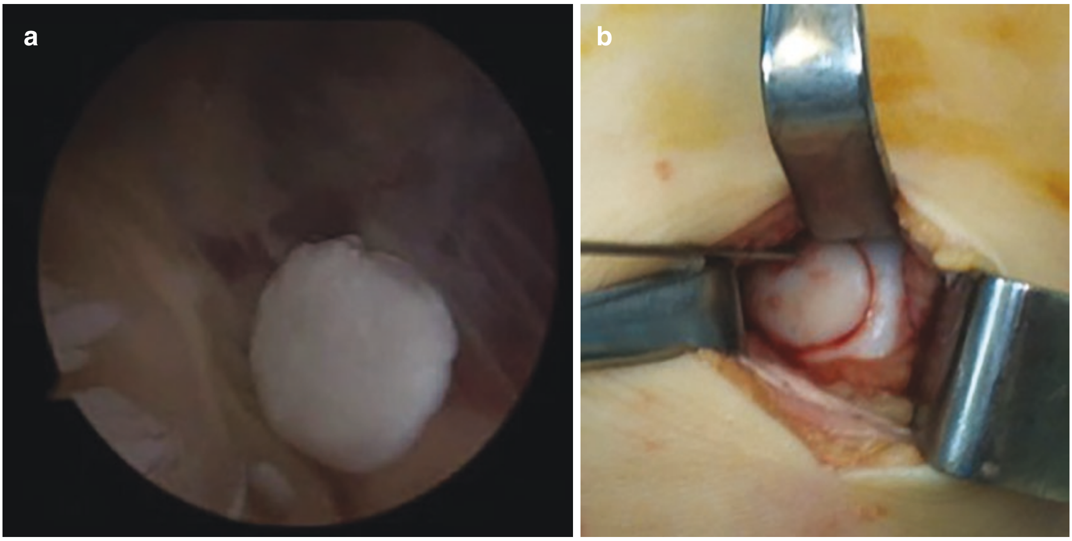

Fig. 34.4 Arthroscopic image of a chondral fragment after patellar dislocation found in the lateral gutter (**a**). The fragment was fixed successfully (**b**), temporary fixation during the operation with a K-wire, before the final fixation using one bioabsorbable screw

(MPFL) reconstruction, patellar realignment, and trochleoplasty, either alone or in combination, if needed, are as essential as the chondral reconstructive procedures, not only in chronic but in acute cases as well (Farr et al. 2012; Lording et al. 2014).

It is well known that over time, these injuries may progress to degenerative joint disease due to the inability of a focal chondral or osteochondral lesion to heal. A variety of articular cartilage reconstructive techniques are available, depending mostly on the defect size. Partial thickness lesions (grade II and III, Outerbridge classification) with a surface area of less than 1 cm^2 may only require chondroplasty. For larger partial thickness lesions (up to 2 cm^2) and/or small full-thickness lesions (1 cm^2, grade IV, Outerbridge classification), bone marrow stimulation techniques (microfracture, drilling) may be useful. With such lesions in the patellar weight-bearing area, it is technically more difficult to perform microfractures than at the femoral condyles, especially during knee arthroscopy. In addition, unfavorable results have been reported using this technique at the patella and for small- to medium-sized lesions (1 to 4 cm^2) (Fu et al. 2005; Kreuz et al. 2006).

For full-thickness lesions of this size (1 to 4 cm^2), osteochondral autograft transfer (OAT, “mosaicplasty” technique) has been used, although some reports have shown less encouraging results, and osteochondral transfer is technically difficult at the patella (Bentley et al. 2003; Bobić 1996; Hangody et al. 1997). Cell therapy options have been used for the treatment of larger lesions (2 to 10 cm^2, grade III and IV, Outerbridge classification) (Alford 2005; Browne et al. 2005; Cole and Cohen 2000; Henderson and Lavigne 2006; Farr 2007; Fu et al. 2005; Knutsen et al. 2004; Minas 2001; Minas and Bryant 2005; Peterson et al. 2003). The most commonly applied method is autologous chondrocyte implantation (ACI), which is a two-stage procedure (first stage, arthroscopy, lesion inspection, cartilage biopsy, and cell expansion; second stage, cells or cells plus scaffold implantation) (Siebold et al. 2014). The use of cell-free scaffolds to cover the lesion site especially after bone marrow stimulation techniques has been also reported (Kon et al. 2014). One-stage cell-based procedures using articulated juvenile allograft articular cartilage have also been described (Farr et al. 2014; Tompkins et al. 2013). Finally, stem cell treatment has potential for articular cartilage repair. Bone marrow-derived, adipose-derived, and synovial membrane-derived stem cells have been known to be capable of producing hyaline cartilage. There are only few clinical trials, but with promising results (Gobbi et al. 2017; Nakamura et al. 2014; Saw et al. 2011). All of the abovementioned methods can be performed through arthrotomy combined with semi- or full inversion of the patella. To obtain optimal results the ideal patient is the younger individual, presenting with one focal lesion, with a short time from the onset of symptoms, with few dislocations and preferably none or just one previous attempt at treatment of the articular cartilage defect repair. Alternatively to cell or scaffold based techniques, large deep lesions with significant subchondral bone erosion may be treated with an osteochondral allograft (Bugbee and Convery 1999; Torga Spak and Teitge 2006).

34.4 Outcomes

34.4.1 Clinical Outcomes

It has been reported that after a first-time patellar dislocation, the risk of symptoms of pain and/or recurrent dislocation is present in approximately 30–50% (Hawkins et al. 1986). Chondral lesions of the patella have generally worse outcomes compared with similar lesions in other knee compartments, but there are only a few available studies. Intra-articular osteochondral fractures accompanied patellar dislocation and/or instability further complicate knee fuction, leading to worse long-term outcomes. Cash and Hughston (1988) observed that when intra-articular loose bodies were surgically removed after patellar dislocation, better clinical outcomes were observed. Nikku et al. (2005) identified the presence of loose bodies as a significant predictor of worse clinical outcomes. Metzler et al. (2015) reported very good clinical results 7 months post-surgery in a case report with a significant articular cartilage lesion to the medial patellar facet treated with microfracture combined with platelet-rich plasma and allogenous articular cartilage graft use. Jalan et al. (2014) reported good clinical outcomes 2 years post-surgery in a case report following screw fixation of both patellar and lateral femoral condyle osteochondral fractures. Callewier et al. (2009) reported excellent clinical outcomes 1 year after pinning of a large osteochondral defect of the lateral femoral condyle-after patella dislocation-in a 23-year-old man. In their report of two cases, Kumahashi et al. (2014) reported good clinical outcomes 2 years after bone screw technique for fixation of osteochondral lesions at the medial facet of the patella. Gkiokas et al. (2012) in their case series (18 patients) reported good clinical outcomes 10 weeks post-surgery following treatment of osteochondral fractures with bioabsorbable pins. Lee et al. (2013) in a similar case series reported that patients who had small osteochondral defects treated with excision and microfracture had better outcomes than patients with larger defects treated with pinning 3 years after surgery. This finding was suggested to be related to the injury severity and not with the treatment. Siebold et al. (2014) in their case series of 13 patients treated with MPFL reconstruction and ACI reported 80% satisfactory clinical outcome 2 years after surgery.

34.4.2 Chondral Lesion Progression

Nomura and Inoue (2004) reported that patients with recurrent patellar dislocations suffer from progressive chronic articular cartilage changes as a result of increased chondral lesion size or severity following the initial injury. Franzone et al. (2012) reported similar results and the chronicity of patellar instability was linked to higher grade and severity of chondral lesions in the patellofemoral joint, especially in trochlear lesions. In another study, they observed that patients with recurrent patellar dislocations had less patellar chondral lesion progression compared with patients who had experienced only one traumatic patellar dislocation (Nomura and Inoue 2005).

According to a study by Gkiokas et al. (2012), pinning of osteochondral defects associated with patellar dislocation in children and young adolescents is likely to achieve full healing. In their 3-year follow-up study, the joint surface appeared intact with only small areas of thinning and no areas of full-thickness loss. Kita et al. (2014) observed no worsening of the chondral lesions after MPFL reconstruction and a significant improvement on International Cartilage Repair Society (ICRS) grading was observed in their short-term second-look arthroscopy follow-up study.

34.4.3 Osteoarthritis

Patients with recurrent patellar instability have a high risk of developing patellofemoral joint osteoarthritis (Sillanpää et al. 2011; Vollnberg et al. 2012).

It has been reported that patients with patellar dislocation treated with traditional nonanatomic procedures have higher risk of developing severe patellofemoral osteoarthritis (Sillanpää et al. 2011). More specifically, Sillanpää et al. (2011) reported a high incidence of full-thickness medial patellar facet articular cartilage lesions. Surgery using nonanatomic procedures does not prevent patellofemoral osteoarthritis. In contrast, more modern techniques, for instance, using anatomic MPFL reconstruction, are associated with less risk of osteoarthritis (Nomura et al. 2007).

34.5 Conclusion

Patellar dislocations and subsequent instability occur predominantly in the young age population. Articular cartilage lesions often occur after acute traumatic patellar dislocation, more frequently affecting the medial facet and/or inferomedial patellar pole and the lateral femoral condyle. The use of MRI scanning after acute patellar dislocation is recommended as standard, especially in the presence of effusion, as the incidence of articular cartilage lesions and loose bodies cannot be reliably diagnosed using plain radiographs. The underlying biomechanical risk factors, such as increased tibial tuberosity-trochlear groove distance, trochlear dysplasia, and patella alta, should be evaluated carefully. As the risk that the chondral lesions will progress to osteoarthritis is high with recurrent dislocations, patellofemoral instability should be addressed along with the articular cartilage lesion treatment. Chondral lesions after patellar dislocation should be restored with articular cartilage fragment refixation, whenever possible. If this is not possible, as in chronic cases, a variety of articular cartilage reconstructive techniques can be used, including bone marrow stimulation, osteochondral transfer, scaffold-based, and cell therapy options.

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Part VI

Arthroscopic Management of Ankle Fractures

Arthroscopy-Assisted Syndesmotic Reduction in Ankle Fractures

35

Gaston Slullitel, Daniel Slullitel, and Valeria Lopez

35.1 Introduction

It is estimated that 10% of all ankle fractures and 20% of operatively treated ankle fractures are accompanied by a syndesmotic injury (Court-Brown et al. 1998; Egol et al. 2010; Riegels-Nielsen et al. 1983; Seitz et al. 1991; Weening and Bhandari 2005). Syndesmotic injuries, colloquially referred to as "high ankle sprains", account for up to 25% of ankle sprains in athletic populations (Court-Brown et al. 1998). The syndesmotic ligaments effectively prevent lateral fibula translation. Therefore, disruption of one of these ligaments can lead to joint instability and osteoarthritis (Ogilvie-Harris and Reed 1994; Snedden and Shea 2001).

The most frequent ankle syndesmosis injury mechanism is external rotation (Boytim et al. 1991; Heim et al. 2002; Hopkinson et al. 1990; Riegels-Nielsen et al. 1983; Wuest 1997), eversion of the talus, and hyperdorsiflexion (Boytim et al. 1991; Wuest 1997). When an external rotational force is transmitted to the syndesmosis, there is an increased risk of syndesmotic diastasis, especially when the ankle joint axis lies in a neutral position (Hopkinson et al. 1990). Even a 1 mm translational syndesmosis instability can reduce the tibiotalar contact area by 40% and increase tibiotalar contact pressure by 36% (Beumer et al. 2000). Given the injury frequency and increasing necessity for surgical intervention, a more comprehensive anatomic understanding of the ankle syndesmosis is warranted. Complete disruption of the syndesmosis is generally evident on radiographs; however, studies have shown inaccuracy of diagnosing incomplete syndesmotic injuries using traditional radiographic measures (Gardner et al. 2006; Joy et al. 1974; Pettrone et al. 1983; Sarkisian and Cody 1976). These inconsistencies have led to the increased use of other modalities to more accurately diagnose and treat syndesmotic injuries. The need for distal tibiofibular syndesmotic fixation after ankle fractures remains controversial despite the abundance of literature concerning ankle fracture treatment (Van den Bekerom et al. 2007). The quest for the best treatment of acute distal tibiofibular syndesmotic disruption is ongoing. Previous studies have shown that arthroscopic evaluation of distal tibiofibular joint stability is of considerable value in the diagnosis of syndesmosis injuries (Han et al. 2007; Lui et al. 2005; Ogilvie-Harris and Reed 1994; Van den Bekerom et al. 2010). Arthroscopic assistance may offer an important instrument for diagnosing and treating a syndesmotic lesion. The aim of this chapter is to provide an update in terms of the usefulness of arthroscopic assistance for surgical syndesmotic injury management.

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35.2 Preoperative Assessment

Determination of what represents clinically relevant syndesmotic instability remains a challenging problem. Along with the traditional diagnostic modalities, plain and stress radiographs, computed tomography, and magnetic resonance imaging (MRI), arthroscopy may provide a minimally invasive method for detecting even subtle syndesmotic instability. A lack of diagnostic criteria consensus, and questionable reliability and accuracy of clinical diagnostic tests, can result in late or missed syndesmosis injury diagnosis.

35.3 Clinical Assessment

Following acute ankle fracture, the clinical diagnosis of syndesmosis disruption is insensitive and nonspecific. However, when pain on palpation is present over the syndesmosis, this should lead to a strong suspicion of instability. Clinical diagnostic tests aim to reproduce symptoms by applying stress to the syndesmosis (Sman et al. 2013). Syndesmotic instability generally occurs in the coronal, sagittal, rotational, and axial planes, but only coronal and rotational plane instabilities are routinely addressed clinically. The *dorsiflexion with external rotation test* as described by Boytim et al. (1991) is thought to reproduce pain over the ankle syndesmosis ligaments by mimicking the commonly described injury mechanism. The *squeeze test* involves mid-calf compression of the tibia and fibula which is thought to cause separation at the distal tibiofibular joint, in turn increasing tension in the remaining syndesmosis ligament fibres resulting in ankle pain (Miyamoto and Takao 2011). Biomechanical analysis has confirmed distal tibiofibular joint separation when the calf is compressed (Teitz and Harrington 1998). The *fibula translation test* is considered positive when pain is experienced over the syndesmosis or at the deltoid ligament when the fibula is translated with respect to the tibia in the anterior-posterior (sagittal) plane (Ogilvie-Harris and Reed 1994).

In a systematic review by Sman et al. (2013), the diagnostic sensitivity, specificity, and inter-rater reliability of clinical tests to identify ankle syndesmosis injury (anterior drawer, Cotton, dorsiflexion, external rotation, fibula translation, and squeeze tests) were found to be very low although the intra-rater reliability was adequate. The necessity for surgical treatment of the injury becomes immediately clear only when there is frank diastasis confirmed by radiographic means (Cesar de Cesar et al. 2011; Edwards and DeLee 1984; Hunt et al. 2013; Zalavras and Thordarson 2007).

35.4 Radiographic Assessment

Ankle syndesmosis instability assessment is traditionally made based on radiographic parameters (Ebraheim et al. 1997), especially stress radiographs. Radiographic measurements such as tibiofibular overlap, tibiofibular clear space, and medial and superior clear space are of limited value in detecting syndesmotic injury (Beumer et al. 2004; Nielson et al. 2005) probably because each of these parameters depends on ankle rotational alignment (Beumer et al. 2004; Pneumaticos et al. 2002). Due to the inability to reproduce ankle positioning under optimal laboratory conditions, repeated radiographs are also of limited value. In a study by Stoffel et al. (2009), consistently increasing tibiofibular clear space values were found on the lateral stress test in the Weber C groups (both with and without deltoid ligament involvement) and the Weber B with deltoid ligament injury, but the same trend was not evident for Weber B injuries without deltoid ligament involvement. These researchers postulated that the mortise remains stable as long as the deltoid ligament remains intact, independent of the status of the distal part of the anterior-inferior tibiofibular ligament. Therefore, no optimal radiographic measures exist to assess syndesmotic instability (Gardner et al. 2006; Van den Bekerom et al. 2010).

Computed tomography (CT) has shown to be sensitive to assess syndesmotic malreduction (Ebraheim et al. 2003; Gardner et al. 2006; Hsu et al. 2013; Joy et al. 1974; Miller et al. 2009; Muratli et al. 2005; Sagi et al. 2012; Takao et al.

2003; Vasarhelyi et al. 2006). MRI has been found to have the highest specificity and sensitivity for syndesmosis injury diagnosis and is similar to that of arthroscopy (Han et al. 2007; Takao et al. 2003).

35.5 Intraoperative Assessment

The Cotton test was first described by Frederic J. Cotton (1910). With this test a bone hook applies a lateral force in the coronal plane to the distal fibula. During application of this force, the degree of syndesmosis diastases can be assessed using an image intensifier. Lateral fibula movement or mortise widening on intraoperative radiographs are considered positive findings (Stoffel et al. 2009). Both for lateral movement and mortise widening, there is no consensus; the judgment whether it is unstable or stable is to be made by the surgeon. Theoretically, if coronal plane widening is observed on the mortise view, syndesmotic instability is present. However, it remains unclear as to how much displacement is required to detect instability, how much force should be applied to the fibula, and in which exact direction the fibula should be pulled (Candal-Couto et al. 2004). Lui et al. (2005) reported insufficient radiographic and intraoperative stress view sensitivity in diagnosing syndesmotic instability. That study defined instability as 2 mm of diastasis observed arthroscopically (Lui et al. 2005). In the same study, the authors observed laxity in more than one plane with the use of arthroscopy. This finding was, however, not evident on intraoperative stress radiographs.

35.6 Arthroscopic Assessment

Accurate syndesmotic injury diagnosis using non-invasive methods is far from precise. To date there is no gold standard method when assessing a suspected syndesmotic lesion. During ankle arthroscopy, anterior syndesmosis injury may be confirmed with greater certainty (Han et al. 2007; Takao et al. 2003). Torn parts of the anterior syndesmotic ligament can often be observed. Inserting a probe into the distal tibiofibular joint can effectively assess syndesmosis integrity (Beumer et al. 2006). Lui et al. (2005) used intraoperative stress fluoroscopy and ankle arthroscopy to examine 53 patients with syndesmotic instability. Sixteen patients (30.2%) had positive intraoperative stress radiographs, while 35 (66%) had positive arthroscopic findings of syndesmotic instability. When assessed arthroscopically, only 2 of the 16 patients that had positive stress radiographs had pure coronal plane instability. Ten of the 16 patients had associated sagittal plane instability, and 4 of 16 had multiplane instability. The investigators concluded that ankle arthroscopy was superior to intraoperative stress fluoroscopy for detecting syndesmosis disruption.

Takao et al. (2001) evaluated 38 Weber B ankle fractures in 38 patients to determine whether syndesmotic instability was present. The investigators reviewed anteroposterior and mortise radiographs as well as ankle arthroscopy in each fracture case. Syndesmotic disruptions were observed in 16 ankles (42%) using anteroposterior radiographs, 21 (55%) using mortise radiographs, and 33 (87%) using ankle arthroscopy. Ankle arthroscopy was superior to plain radiography for diagnosing syndesmotic disruptions. In a later study, Takao et al. (2003) also reported improved rates of diagnosing syndesmotic disruptions among 52 patients with acute ankle fractures. Accuracy in diagnosing syndesmotic injuries occurred in 63% of patients when plain radiography was used compared with 100% accuracy using ankle arthroscopy (Takao et al. 2003). The advantages associated with direct visualization of the disrupted syndesmosis are clear. However, there is still little consensus in terms of the amount of force needed to create syndesmotic diastasis in each plane, assuming that instability probably occurs in more than one plane.

In a cadaveric study by Watson et al. (2015), when the anterior syndesmosis and lateral ankle ligaments were disrupted in a cadaveric specimen, multiplanar ankle syndesmosis instability was visible in every specimen with as little as 2 lb. (0.9 kg) of force. Although the lateral ankle ligament complex is not part of the syndesmosis, they observed lateral ankle ligament incompetence in the presence of partial syndesmotic instability. This relationship has, however, not been clearly studied in the literature. It has been hypothesized that increased fibula movement within the incisura may represent a role of the lateral ankle ligament complex in securing the distal fibula in the face of syndesmotic disruption.

35.7 Treatment

Anatomic joint surface reconstruction is a tenet of periarticular fracture care well known to orthopaedic surgeons. This dogma has been supported by data pertaining to articular fractures of many varieties. In the matter of fixing the syndesmosis, clinical studies have associated screw placement with syndesmotic malreduction in 22–52% of cases (Miller et al. 2013; Phisitkul et al. 2012). In a study by Phisitkul et al. (2012), malreduction increased with sequential syndesmotic destabilization. Ankle arthroscopy in the setting of acute operative management provides a mean of achieving complete intra-articular visualization and management of potential pathologic findings (Sri-Ram and Robinson 2005). The advantage of this technique is that it provides assessment of different planes of instability and assists anatomic reduction of the syndesmosis. Syndesmotic stabilization without direct visualization has a high percentage of malreduction (Miller et al. 2009). Takao et al. (2003) advised that ankle arthroscopy is indispensable for the accurate diagnosis of a syndesmosis tear, while Sri-Ram and Robinson (2005) suggested that arthroscopy should be considered as a part of syndesmotic injury management where conventional imaging techniques fail to identify syndesmotic disruption.

Arthroscopic observation of a ruptured anterior syndesmotic ligament does not completely verify that there is syndesmotic instability because the interosseous ligament and the interosseous membrane cannot reliably be assessed during ankle arthroscopy. In most supination external rotation (SER) IV ankle fractures, although the anterior and posterior syndesmotic ligaments are ruptured, syndesmotic instability is rare (Lauge-Hansen 1950). Even when the diagnosis has been established by clinical and/or intraoperative tests, there seems to be no consensus about the optimal management of these fractures (Boden et al. 1989).

Fixation devices used to repair syndesmotic lesions are currently inserted in alignment with the neutral anatomic plane (approximately 30° posterior to the coronal plane), parallel to the plafond, 2–5 cm proximal to the joint line with reduction forceps placed on the lateral malleolar ridge of the fibula, and at the central point of the medial tibial cortex (McBryde et al. 1997; Miller et al. 1999). According to several anatomic studies (Ebraheim et al. 2006; Sarrafian and Kelikian 2011; Schepers 2011), such placement is within the interosseous tibiofibular ligament (ITFL) footprints and safely avoids the synovial-lined joint space including the articular cartilage of the tibia and fibula. This placement may, however, not optimally restore the ligament footprints and native syndesmosis anatomic characteristics.

Although it remains controversial which is the best fracture reduction method, concerns also exist in terms of the most optimal fixation method to use. The suture-button syndesmosis fixation technique has emerged as an alternative to screw fixation (Thornes et al. 2005). Theoretically, this device allows for physiologic micromotion while maintaining an accurate reduction because a certain amount of positional variance is allowed. Even though the suture-button system was initially presented as a device that did not need removal, the rate of implant removal might be as high as 25% (Thornes et al. 2005). Previous biomechanical investigations have demonstrated similar mechanical strength of a suture-button repair and a syndesmotic repair with the use of three- and four-cortex screws (Ebramzadeh et al. 2013; Seitz Jr et al. 1991). A systematic review showed similar American Orthopaedic Foot and Ankle Society (AOFAS) outcome scores for treatment with the endo-button system (mean = 89 points) and screw fixation (mean = 86 points) (Naqvi et al. 2012a, b). Besides discussion on which diameter, placement height, and number of cortices, the need for routine syndesmotic screw removal has frequently been subject to debate. This is fed by fear of screw breakage and expected range of motion limitations (Thornes et al. 2005). In a recent review the functional outcome did not differ in cases with retained or removed syndesmotic screws (Schepers 2011). Discussions are ongoing with regard to whether one or two suture buttons should be used and in what configuration. Naqvi et al. (2012a, b) placed a second extra-capsular suture fixation device in 26% of their patients. DeGroot et al. (2011) used more than one device in 75% of their patients. Consistent with recent literature, it is suggested that general radiographic criteria for syndesmotic fixation are of limited value compared with the intraoperative impression of the syndesmotic stability in all operated ankles (Ebraheim et al. 2003; Naqvi et al. 2012a, b). Preoperative planning is essential but not sufficient to determine the necessity for syndesmotic fixation.

35.8 The Authors' Preferred Method

When a patient presents with a suspected syndesmosis lesion, the physical examination includes inspection for swelling and tenderness at the level of the syndesmosis, evaluation of ankle alignment, and the specific syndesmotic stress tests as described. Comparative standard weight bearing (if tolerable) anterior-posterior, lateral, and mortise radiographs are made in all patients. Further assessment of signs indicating syndesmotic instability is performed. These are unilateral absence of tibiofibular overlap in the anteroposterior radiograph (Beumer et al. 2004) and a medial clear space that is larger than the superior clear space. Moreover, particular attention is placed on the distance between the medial fibula and the deepest point of the tibial incisura (not to exceed 5 mm) and compares this measure with the healthy ankle (Pneumaticos et al. 2002).

When a syndesmotic lesion is suspected, a 1.5 Tesla MRI is obtained. Torn anterior-inferior tibiofibular ligament (AITLF) or posterior-inferior tibiofibular ligament (PITLF) in the axial plane and a bone bruise in the STIR images in the margins of the incisura fibularis in the tibia are checked for. The deltoid ligament is also evaluated for the presence of any oedema between the fibres or the absence of fibre pattern in the coronal T1 plane view. Ankle arthroscopy in conjunction with all ankle fractures that require open reduction and internal fixation is performed. Both arthroscopic and open surgical procedures are performed with the patient in the supine position under regional anaesthesia. The patient is positioned on a standard operating table with the heel at the end of the table. A bump is placed under the ipsilateral hip to optimize positioning for both arthroscopic and open lateral approaches to distal fibular fractures. A proximal thigh tourniquet aids visualization during arthroscopic and open procedures while avoiding leg compression. Care is taken to identify the relevant surface anatomy for arthroscopy: medial malleolus, tibialis anterior, superficial peroneal nerve, and peroneus tertius (Fig. 35.1). The joint is pre-insufflated with 10–15 mL of arthroscopy fluid using an 18 gauge needle at the level of the intended anteromedial portal, and intra-articular placement is confirmed by lateral joint distention. A skin incision is made over the anteromedial portal, and blunt dissection is carried down to the capsule. A cannula with a blunt trocar is introduced and directed towards the lateral malleolus; however, anatomic distortion may be present due to the injury. A 4.0 mm 30° arthroscope is used, and joint irrigation should be supplied by gravity or low-pressure inflow (20 mm Hg) to mitigate excessive fluid extravasation. The anterolateral portal position is confirmed with an 18 gauge needle and established in the same manner as the anteromedial portal. The anteromedial portal is primarily used for viewing and the anterolateral portal for instrumentation; however, the surgeon may use either portal for both purposes. A 3.0 mm arthroscopic shaver (Arthrex, Naples, FL) is introduced, and haematoma and fibrous tissue are debrided. Joint visualization should include the (1) anterior tibial lip, (2) lateral malleolus, (3) lateral ankle ligaments, (4) lateral talar dome and shoulder, (5) syndesmosis, (6) central talus and posterior tibial plafond, (7) medial malleolus, (8) deltoid ligament, and (9) medial talar dome and shoulder. Common findings include disruption of the anterior-inferior tibiofibular ligament, loose bodies, and osteochondral lesions of the talus and tibial plafond, interposition of the posterior tibial tendon at medial malleolar fracture sites, and fragmentation of the posterior lip of the tibial plafond with disruption of the posterior tibiofibular ligament. Thorough documentation of chondral injury is performed throughout the arthroscopic procedure. Transchondral fractures are typically managed with debridement and removal of loose bodies, chondroplasty to bleeding bone with a 3.0 mm arthroscopic shaver (Arthrex, Naples, USA), or curettage and microfracture with a chondral awl (Arthrex, Naples, USA) to a depth of 6 mm. The syndesmosis is evaluated by visualizing the tibiofibular joint while an external rotation force is applied. Opening of the joint by more than 2 mm is suggestive of injury; however, fluoroscopic stress examination is relied on to guide the need for syndesmotic fixation (Fig. 35.2). Also, the arthroscopic probe is inserted and turned around the syndesmosis easily if the ligament is damaged. After arthroscopy, the thigh holder is removed, and open reduction and internal fixation can be performed without repositioning the patient. Fixation using a TightRope (Arthrex, Naples, USA) from lateral to medial with a 30° inclination from posterior to anterior is used. If the deltoid ligament is torn or detached from the medial malleolus (Fig. 35.3), it is reattached using two 3.5 mm anchors (Arthrex, Naples, USA) prior to syndesmosis fixation.

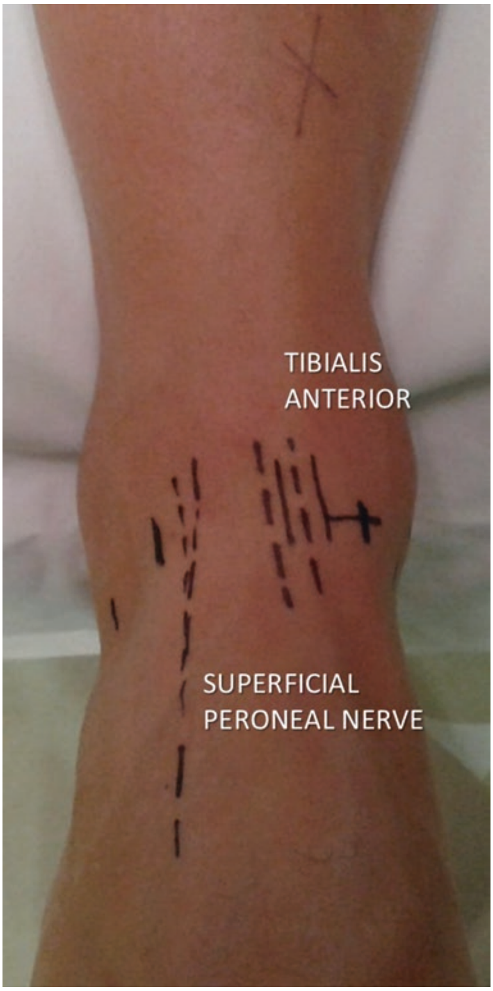

Fig. 35.1 Preparation of skin landmarks, note that the tibialis anterior is marked both in plantar flexion and dorsiflexion. The tips of both malleoli are also marked, as well as the course of the superficial peroneal nerve

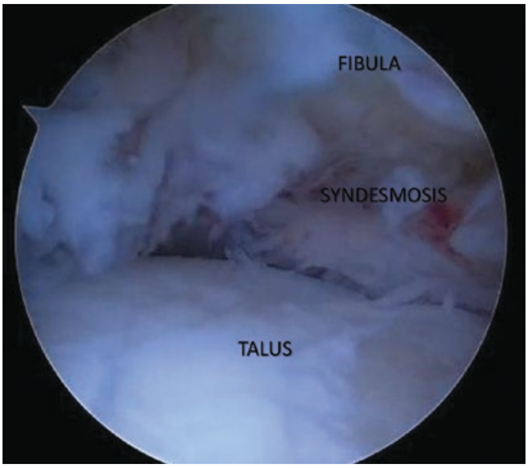

Fig. 35.2 Arthroscopic view of the ankle syndesmosis. In cases of not evident diastasis, a 3 mm probe is inserted and easily rotated around the syndesmosis if the ligament is damaged

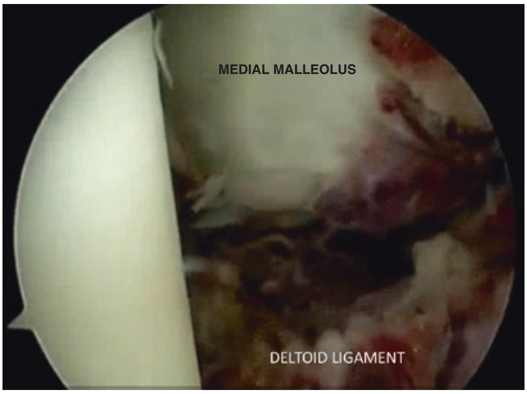

Fig. 35.3 Assessment of the deltoid ligament state is important. If torn or detached, it is reattached using anchors

35.9 Conclusion

The use of arthroscopy in the setting of ankle fractures is not routine for most surgeons, and there is insufficient evidence from which to derive specific indications (Glazebrook et al. 2009). Arthroscopic assistance in the setting of a syndesmotic lesion has the advantage of assessing not only instability and verifying reduction quality but also for a thorough assessment of associated injuries such as a deltoid ligament lesion, transchondral fracture, or the presence of loose bodies. It is likely that a combination of clinical and imaging tests and inclusion of symptoms and the patient's history might further assist in diagnosis and treatment.

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36

Minimally Invasive Fixation of Complex Intra-articular Fractures of the Distal Tibial Plafond

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The term "pilon" ("pestle" in French) was first used by the French radiologist Destot (1911) because of the resemblance of the distal tibia to the pestle used by pharmacists. He described the way the talus is driven into the articular surface of the distal tibia, similar to the operation of a hammer. "Plafond" ("ceiling" in French) was introduced to define either a fracture of the distal tibial articular surface or the roof of the ankle joint (Bonin 1950). Plafond fractures, intra-articular fractures of the distal tibia, represent approximately 1% of all lower-extremity fractures and 5–10% of all tibia fractures (Marsh and Saltzman 2001). These are usually high-energy fractures characterised by articular comminution, severe soft tissue injury, and axial compression forces acting on the articular surface of the distal tibia (Brumback and McGarvey 1995). Prior to the publication of a landmark paper in 1979, these fractures were commonly treated using calcaneal traction, which inevitably caused stiffness and arthritis (Ruedi and Allgöwer 1979).

The primary goals of treatment of plafond fractures are to maintain a functional ankle joint by re-establishing the weight-bearing surface and restoring the alignment of the extremity. Although the most important factor affecting the outcome in surgically treated patients is the quality of the reduction (Korkmaz et al. 2013), the surrounding soft tissue envelope must also be considered, along with alignment, bone stability, and joint mobility (Tarkin et al. 2008). Treatment options include closed reduction, unilateral or circular external fixation, and open reduction and internal fixation (ORIF). Primary arthrodesis is an alternative treatment method recommended by some surgeons for severely comminuted plafond fractures (Beaman and Gellman 2014; Bozic et al. 2008).

All treatment options have their advantages and possible disadvantages. With closed reduction, anatomical reduction of the articular surface is almost impossible (Ayeni 1988; Othman and Strzelczyk 2003; Pollak et al. 2003). External fixation techniques that depend on ligamentotaxis for fracture reduction cannot re-establish the articular surface anatomically and do not allow early joint motion (Bone et al. 1993; Saleh et al. 1993). ORIF usually consists of open reduction of the fibula, restoration of the tibiotalar articular surface, buttress plating of the tibia, and bone grafting when necessary. The AO group (Arbeitsgemeinschaft für Osteosynthesefragen, AO Foundation, Davos,

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Switzerland) has reported good results using this algorithm. However, ORIF is associated with a high rate of complications, such as wound dehiscence, infection, and osteomyelitis, due to the relatively limited blood supply in the distal tibia. Soft tissue damage is particularly problematic after high-energy trauma to the distal tibia (Bourne 1989; Pollak et al. 2003; Teeny and Wiss 1993) and can dictate the timing of surgery. The rate of superficial infection following ORIF in tibia plafond fractures has been reported as 27–36% of cases (Dillin et al. 1986). To overcome postoperative complications, such as wound dehiscence and infection, techniques that combine minimally invasive fixation with external fixation were developed (Blauth et al. 2001; Sirkin et al. 2004). Several authors have recently reported arthroscopically assisted reduction and fixation of tibial pilon fractures (Kralinger et al. 2003; McGillion et al. 2007; Poyanli et al. 2012).

Previously, an arthroscopic technique that uses a modified form of the targeting device used for anterior cruciate ligament (ACL) surgery to centre the depressed zone and reduce the chondral lesion by tapping through a window has been described (Poyanli et al. 2012). The following is a detailed description of the technique. A tourniquet is applied to the proximal thigh with the patient, under regional anaesthesia, supine on a radiolucent table. The ipsilateral iliac wing of the patient is draped for surgery as is the graft donor area, and support is placed under the ipsilateral hip to keep the lower extremity in internal rotation. The ankle is distracted using manual traction. In case of a complex and comminuted fracture, fluoroscopy is used, along with an external fixator, which is passed through the calcaneus and the tibia anteromedially using two Schanz screws; ankle distraction can be used as well when indicated. The tourniquet is inflated, and ankle arthroscopy is performed through the standard anteromedial and anterolateral portals (Fig. 36.1). Any haematomas and loose bodies are removed arthroscopically, after which the amount of displacement and articular step-off can be assessed (Fig. 36.2). A modified form of the drill guide (which is smoothed using a rasp) C-ring used for ACL surgery (Arthex®, Naples, FL) is adjusted to reach the centre of the deepest point of the fracture line. A Kirschner (K-) wire is passed antegradely through the extraarticular end of the drill guide in the supramalleolar area at about 40° to the coronary tibial axis (Fig. 36.3). The exit point of the K-wire is checked

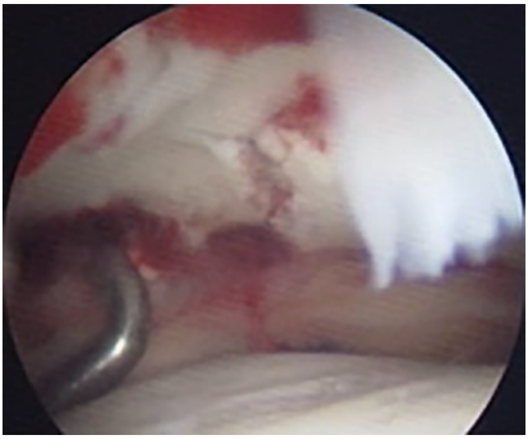

Fig. 36.2 Arthroscopic view of the fracture

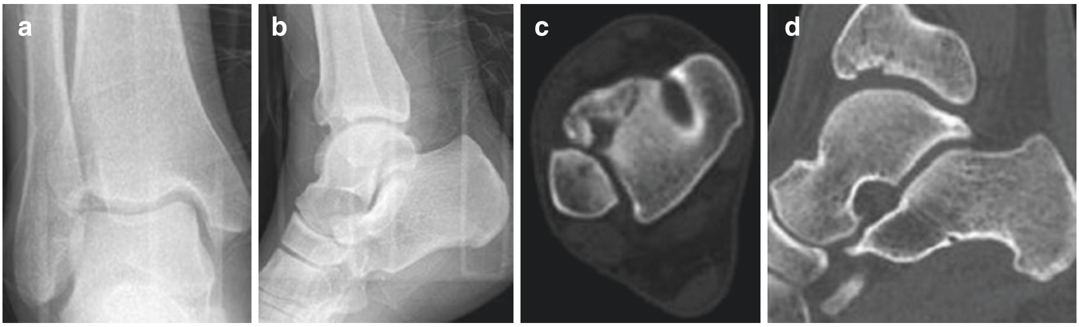

Fig. 36.1 (**a**, **b**) Radiographs of a split depression type plafond fracture. (**c**, **d**) Axial and sagittal computed tomography images of the same patient

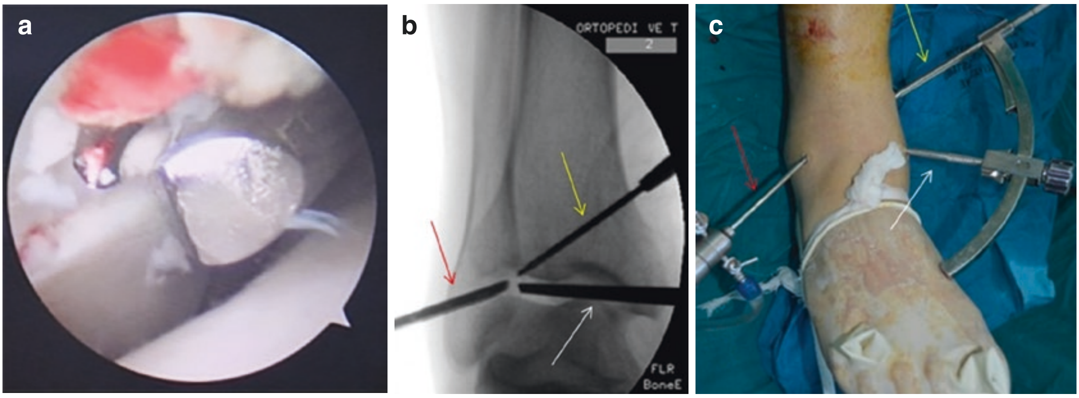

Fig. 36.3 (**a**) Arthroscopic view of the fracture with the guide wire centred in the joint. (**b**, **c**) Fluoroscopic and clinical views of the guide wire positions (white arrow), arthroscope (red arrow), and drill bit (yellow arrow)

arthroscopically, and then it is advanced 1 mm past the joint (Fig. 36.3). After the K-wire is fixed in the bone, the appropriate 7, 8, or 9 mm drill is used to drill a hole approximately 1 cm from the subchondral bone line (or fracture fragment) over the K-wire. As the guide wire is removed from the joint, the displaced articular fragment is reduced with gentle tapping using a tunnel dilator (AR-1854; Arthrex®) (Fig. 36.4). Simultaneously, a probe is used to apply a counterforce to the areas with displacement potential. Joint restoration and reduction are checked arthroscopically and fluoroscopically (Fig. 36.5). The tunnel dilator is then used to push the bone graft harvested from the ilium to above the fractured fragment in the tunnel. With the other end of the guide at 40° to the tibial axis in the tunnel and the C-ring adjusted to 130°, a cannulated bioabsorbable screw is sent through the guide over a K-wire passing in close proximity to the graft to prevent redisplacement. Because the guide is set at 130°, a screw can easily be placed parallel to the joint line to support the graft (Fig. 36.6). The reduction can be fully evaluated using computed tomography (CT) (Fig. 36.7). Finally, the tourniquet is deflated, and the external fixator is removed. A similar technique may be used for AO/OTA other tibial pilon fractures (Fig. 36.8). In some cases, fixation of the fibula may be necessary before fixation of the plafond fracture. After arthroscopic evaluation and placement of the ACL guide as described above, gentle reduction is performed using the tunnel dilator (Fig. 36.9). After the procedure, the joint is again checked arthroscopically, and a distal tibial plate is placed to maintain fixation using a minimally invasive technique (Fig. 36.10).

Many options are available in terms of the treatment of tibial pilon fractures. The surgeon selects the correct treatment according to the fracture type and the condition of the soft tissue envelope (Calori et al. 2010). Non-surgical treatment options such as closed reduction, skeletal traction, and immobilisation using a cast may lead to unsatisfactory results, due to decreased joint mobility and symptoms of early arthrosis owing to insufficient restoration of the articular surface (Ayeni 1988; McGillion et al. 2007). Ruedi and Allgöwer (1979) outlined the classic pilon fracture treatment principles as restoration of the fibular length, anatomic reduction of the tibial articular surface, bone grafting for metaphyseal defects, and medial buttress plating. The most common disadvantages of ORIF are soft tissue complications (Blauth et al. 2001; Sirkin et al. 2004; Teeny and Wiss 1993). In cases of comminuted fractures (e.g. AO/Orthopaedic Trauma Association type 43-C3) with concomitant severe soft tissue injury, definitive treatment to stabilise the bone can be delayed until the soft tissues recover. Operative trauma often exacerbates the compromise to the soft tissues caused by the trauma; therefore, multiple surgical interventions should be staged.

Fig. 36.4 (**a**) A tunnel is drilled over the K-wire. (**b**) Reduction with gentle tapping using a tunnel dilator. (**c**, **d**) Anterior-posterior and lateral fluoroscopic view of the reduction with the tunnel dilator

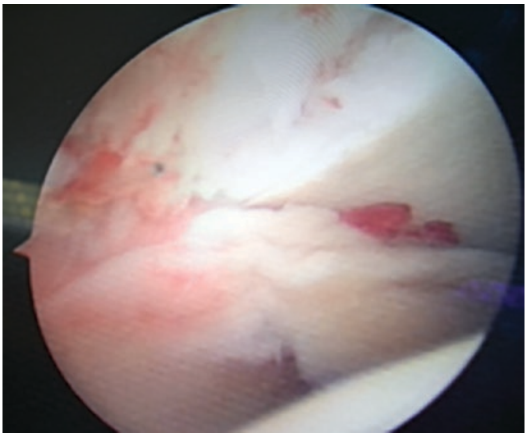

Fig. 36.5 Arthroscopic view after reduction

First, temporary fixation is achieved with external fixators. After the soft tissues recover, ORIF with plate fixation can be applied (Blauth et al. 2001; Patterson and Cole 1999; Sirkin et al. 2004). Arthroscopy is a minimally invasive technique that is used for diagnostic procedures and surgical treatments. Arthroscopy-assisted fracture treatment is gaining popularity (McGillion et al. 2007; Poyanli et al. 2012). Miller (1997) reported the first case of arthroscopically assisted fixation of a Tillaux fracture in an adult. The concept of the "cortical envelope" refers to the outer rim of the tibia on axial CT images and has been well defined for tibial plateau fractures (Levy et al. 2008). The authors and others have had success with arthroscopic techniques in cases where the

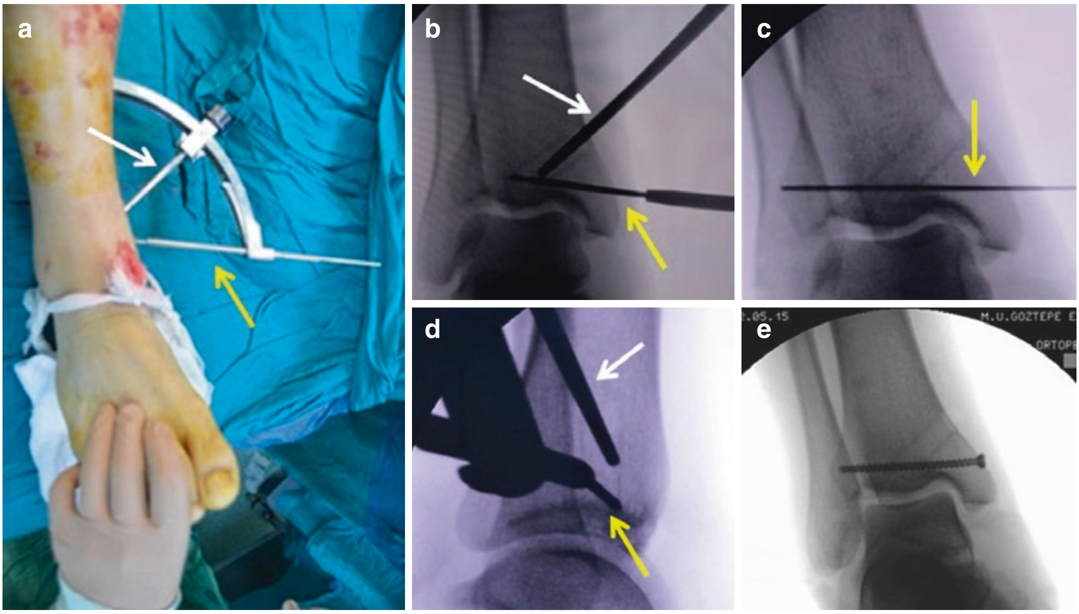

Fig. 36.6 (**a**) Placement of the guide at an appropriate angle so that the screw will be parallel to the joint line. (**b**–**e**) Fluoroscopic view of the K-wire inserted into the modified anterior cruciate ligament guide in the anterior-posterior and sagittal planes parallel to the joint. Fluoroscopic view of the screw supporting the graft parallel to the joint line (white arrow, guide wire; yellow arrow, K-wire guiding the screw's position)

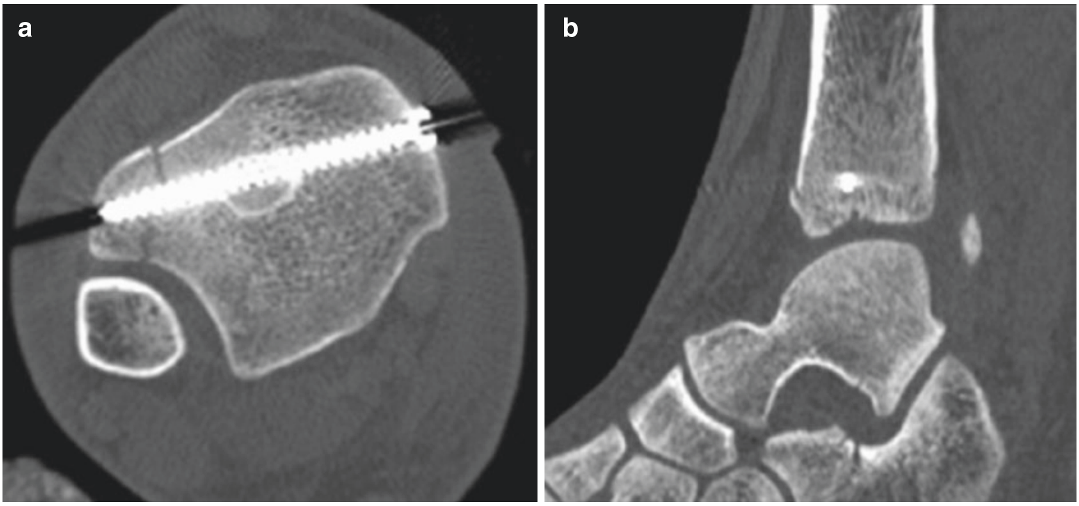

Fig. 36.7 (**a**, **b**) Axial and reformatted sagittal computed tomography (CT) images of the fracture after surgery (Note the precise placement of the screw). (**c**, **d**) Reformatted 3D CT images of the patient (Note the screw keeping the graft in place)

cortical envelope is intact or can be easily restored with a clamp (Fig. 36.11). With the technique mentioned above, a plate is used to restore fibular length. Following arthroscopic assessment of the plafond fracture, articular reduction is performed at the supramalleolar level using a transtibial tunnel opened antegradely, using an ACL drill guide. This minimally invasive approach does not compromise the blood supply and greatly decreases the

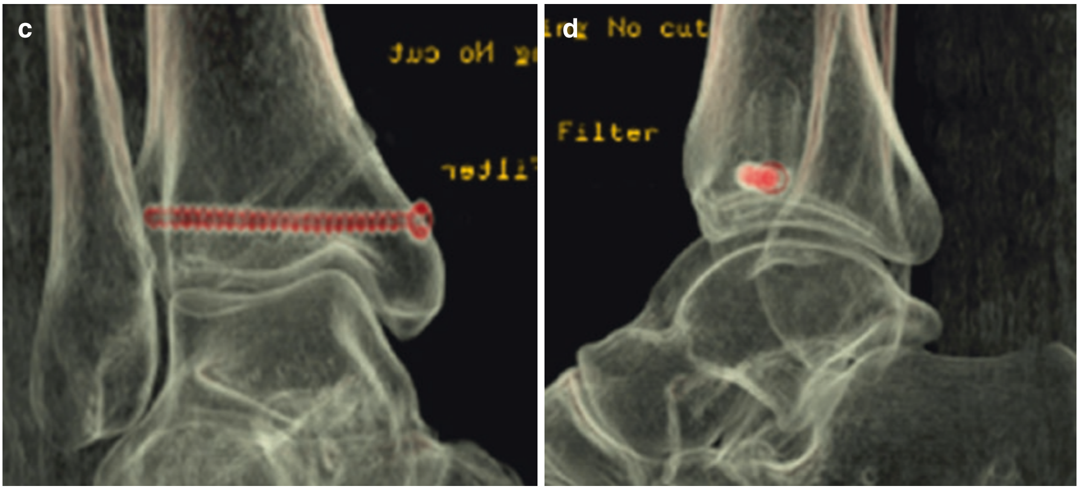

Fig. 36.7 (continued)

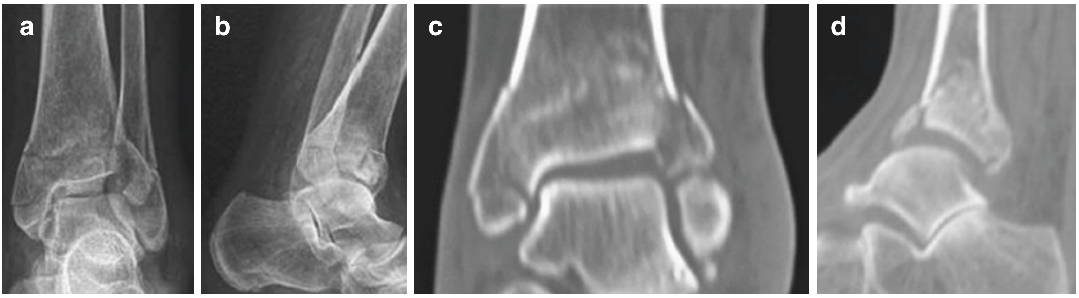

Fig. 36.8 (**a**, **b**) Preoperative radiographs of an AO/OTA-type 43 B3 fracture in a 66-year-old female patient. (**c**, **d**) Preoperative reformatted coronary and sagittal CT images

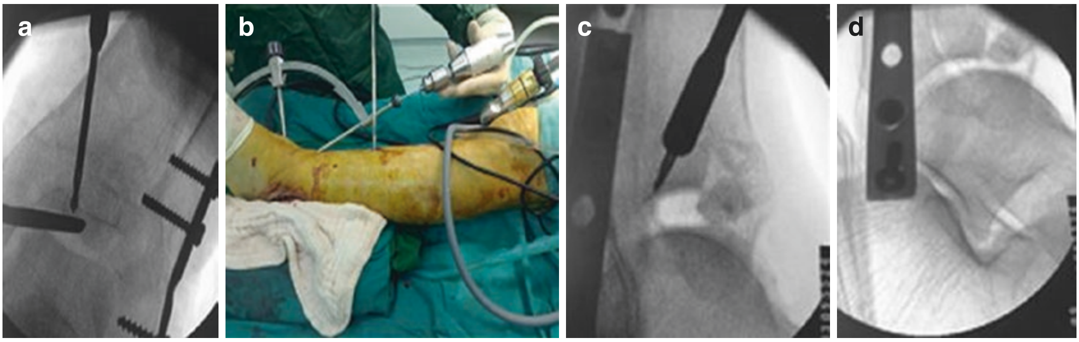

Fig. 36.9 (**a**, **b**) Intraoperative fluoroscopic and clinical views during placement of the anterior cruciate ligament guide. Fluoroscopic view during (**c**) and after (**d**) reduction using the tunnel dilator

duration of fluoroscopy. It is also a faster method for fixation and grafting (when necessary) the articular fracture segment. A transtibial tunnel can be used for fracture reduction and grafting at the supramalleolar level without requiring joint exploration. This method causes fewer complications than the open reduction technique, such as wound dehiscence and infection, and allows accurate fracture reduction while maintaining joint congruity under direct visualisation.

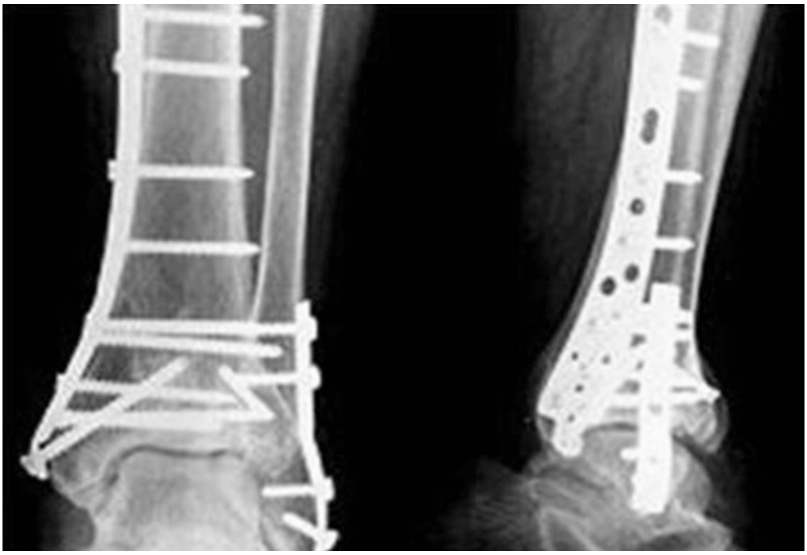

Fig. 36.10 Radiographs of the patient in the previous image at 1 year postoperatively

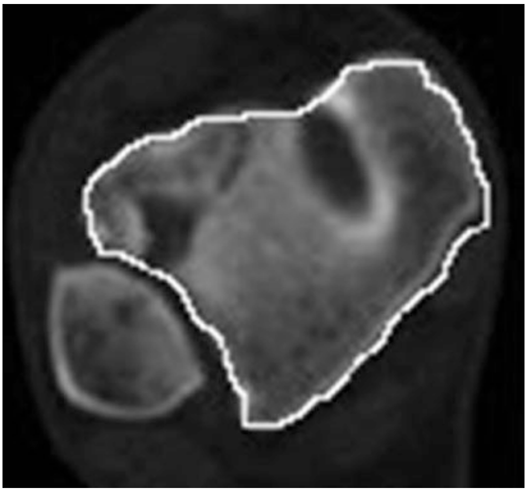

Fig. 36.11 Image demonstrating the “cortical envelope” theory

36.1 Conclusion

The technique described in this chapter involves supporting the core graft with a screw placed nearly parallel to the joint line using a guide without fluoroscopy. Image-guided interventional procedures may lead to occupational radiation exposure, and guidelines have been established to protect medical staff and patients. Limiting the radiation dose by decreasing the fluoroscopy time is essential for decreasing radiation exposure (Heron et al. 2010). This technique, using a modified ACL guide, substantially decreases fluoroscopy duration.

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37

Arthroscopic-Assisted External Fixation of Pilon Fractures

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37.1 Introduction

Pilon fractures are one of the most difficult fracture types. The term "pilon fracture" is French for pestle and describes intra-articular fractures of the distal tibia. The French radiologist Etienne Destot (1911) first described the pilon fracture, also named plafond fractures. There is a variable degree of displacement and/or comminution in the metaphyseal area and articular surface of the distal tibia. These fractures comprise approximately 10% of all lower limb fractures and are far more common in males (the average age is 35–45 years) (Mauffrey et al. 2011; Sivaloganathan et al. 2017). Typically, they result from high-energy trauma with predominantly axial loading and rotational forces to the distal tibia. The rotational component of the injury results in spiral fracture of the metaphyseal area, and axial compression results in articular surface separation or comminution, for instance, after a traffic accident or fall. They can also occur in older patients through a low-energy trauma, related to osteoporosis.

Pilon fractures of the tibia are severe injuries often involving injury to the surrounding soft tissue. Subsequently, the risk of soft tissue complications is high. The lack of musculature around the distal tibia as well as the poor vascularity of this segment of the tibia makes these injuries prone to complications. During the last decade, there is a trend toward minimally invasive surgical techniques. Within this context, ankle arthroscopy may in some patients be an important technique in surgical management to improve postoperative patient outcomes.

37.2 Classification

Various classifications have been proposed to classify fractures. These classifications are mainly descriptive, and none of them has a prognostic value. The two most commonly used are the Ruedi and Allgöwer system (Ruedi and Allgöwer 1979) and the AO/OTA classification system (Kellam et al. 2018) (Figs. 37.1 and 37.2). Currently the Ruedi and Allgöwer system has largely been replaced by the AO/OTA classification system and is now the most widely used system for these fractures (Marsh et al. 2007). According to this system, distal tibial fractures are divided into the following categories: type A, non-articular fractures; type B, partial articular fractures; and type C, total articular fractures. Each class is subcategorized into three groups based on the amount of com-

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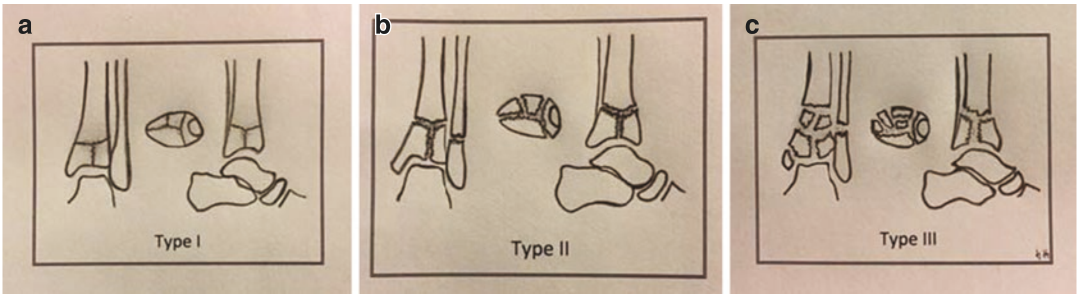

Fig. 37.1 The Ruedi and Allgöwer system: (**a**) type I, without significant displacement; (**b**) type II, significant displacement, but minimal comminution; (**c**) type III, severe comminution and significant intra-articular displacement

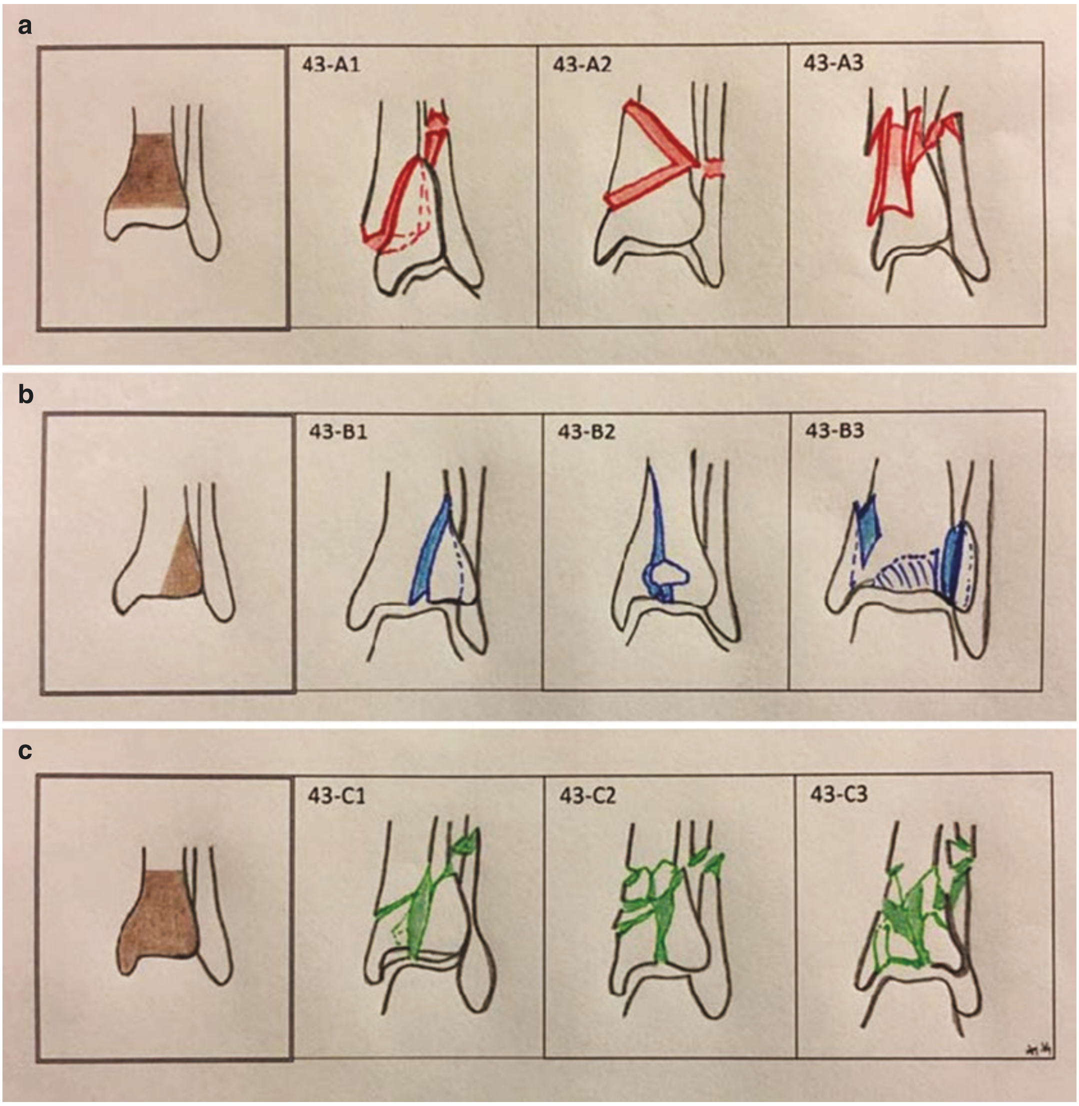

Fig. 37.2 The AO classification system. (**a**) 43-A extra-articular, A1 simple fracture, A2 wedge fracture, A3 multifragmentary fracture; (**b**) 43-B partial articular, B1 pure split fracture, B2 split depression fracture, B3 multifragmentary depression fracture; (**c**) 43-C complete articular, C1 simple articular with simple metaphyseal fracture, C2 simple articular with multifragmentary metaphyseal fracture, C3 complete multifragmentary articular and metaphyseal fracture

minution, and these groups are then further divided into three subgroups by other characteristics of the fracture description based on direction and fracture line location. Subsequently, there is a large number of subgroups (27 in total), which decreases the value of the system, as this number of subgroups is difficult to interpret for prognostic value. Additionally only four subgroups (type B3, C1, C2, C3) are actual pilon fractures of the distal tibial articular surface.

37.3 Imaging

Standard radiographs are anteroposterior, lateral, and ankle mortise views. Following provisional reduction of the fracture in the emergency room, repeat radiographs are helpful and must be obtained in every case. Any suspicion about proximal extension of the fracture line indicates that full-length tibia and fibula radiographs should be obtained. CT scanning is often necessary, in order to demonstrate the exact displacement of the articular fragments, as well as the location and degree of comminution. This knowledge is important, especially when using minimally invasive surgical techniques. It provides more information than plain radiographs and can alter the surgical plan.

37.4 Treatment

37.4.1 Initial Evaluation

A careful history including information about the mechanism of injury is vital for correct management of these fractures. Any associated injuries and comorbidities that can affect soft tissue healing and fracture union must be considered. The mechanism of injury provides useful information about the amount of energy applied to the bone and soft tissues. It is important to rule out neurovascular injuries, as these will greatly affect the postoperative functional outcome. Finally the status of the soft tissue envelope should be carefully assessed. Excessive edema and fracture blisters (clear fluid-filled and blood-filled blisters) indicate that the soft tissue envelope has suffered serious damage, and open treatment must be delayed until these signs subside. Fracture blisters that contain blood indicate that there is more serious soft tissue damage compared with fluid-filled blisters. Skin wrinkles are considered reliable indicators that confirm subsidence of limb edema and improving soft tissue conditions (Griffiths and Thordarson 1996; Sanders 1992).

37.4.2 Treatment Principles

The treatment strategy for pilon fractures of the tibia should consider whether or not it represents: an articular injury, metaphyseal disruption that separates the distal tibia from the proximal shaft, and the severity of associated soft tissue injuries. In order to achieve a successful outcome, every surgeon must balance these three features. There are three crucial steps during management: (1) the articular surface must be well reduced, (2) the angular alignment and length of the limb must be restored, and (3) the soft tissues must be protected from further injury (Tomas-Hernandez 2016). The ideal treatment to achieve each of these goals is not the same. Minimizing additional soft tissue injury may not facilitate an exact reduction of the articular surface.

Early publications suggested that anatomic articular surface reduction was mandatory in order to reduce the risk of ankle osteoarthritis and that this was the most important factor for achieving excellent results (Ruedi and Allgöwer 1979). Subsequently the treatment strategy was designed to achieve this goal. Today many surgeons still believe that the concept of an absolute anatomical reduction of the articular surface is the one most critical factor for a successful outcome. On the other hand, there is a growing body of evidence that although anatomical reduction is vital, this alone does not guarantee a successful result. Recent studies have demonstrated that suboptimal articular surface reduction in favor of a soft tissue sparing surgical approach may lead to similar or better results (Bacon et al. 2008; Calori et al. 2010; Meng and Zhou 2016).

Surgical treatment of pilon fractures includes several options: open reduction and internal fixation, minimal internal fixation combined with external fixation, and external fixation alone. Currently, the two main treatment strategies in terms of pilon fractures include staged open reduction and internal fixation and minimally invasive techniques using indirect reduction in order to reduce unnecessary exposure. There are several minimally invasive techniques including a simple application of non-bridging external fixation (such as hybrid external fixators) to a combination of external fixation and minimal open approaches.

Regardless of the choice of definitive treatment, the fibula must always be taken care of in order to restore limb length. Associated soft tissue injury following a pilon fracture generally hampers the use of an acute open surgical approach. In most patients, a substantial delay is recommended during which a bridging external fixator is applied. The delay is usually approximately 7–14 days. A staged treatment strategy with initial bridging external fixation followed by internal fixation using a plate as the second procedure is currently the most employed treatment. The fibula can be fixed during the initial application of the bridging external fixator or during the second stage of final open treatment. Fibula fixation timing depends on many factors, such as the location of the comminuted tibia fracture, as this is a primary surgical approach determinant.

Recent minimally invasive techniques carry several advantages compared with open treatment. Using hybrid external fixation, it is possible to operate earlier than by using plates since the status of the soft tissues is not as crucial to proceed as in open treatment, and additionally there is no (or less) need for a second operation. The most important advantage of these minimally invasive approaches is the lower risk of postoperative complications such as infection, skin necrosis, and wound dehiscence. The principle of treatment with an external fixator is through ligamentotaxis. Nevertheless, articular surface reduction is suboptimal, and this may result in higher rates of postoperative osteoarthritis. Whether or not the suboptimal reduction leads to poorer functional outcomes is not clear. In order to achieve a more anatomical reduction during external fixation of pilon fractures, arthroscopic-assisted procedures have been included in the treatment strategy.

Luo et al. (2016) used arthroscopy along with a minimal anterolateral or anteromedial approach to minimize soft tissue exposure. They reported successful fracture healing outcomes in all patients with no postoperative complications. Cetik et al. (2007) treated a 42-year-old male patient with a tibial pilon fracture with an arthroscopic-assisted unilateral external fixator and minimally invasive internal osteosynthesis. Arthroscopy was used to help reduce the fracture fragments and restore the joint surface, and the fracture fragments were fixed with screws immediately after being reduced. The authors suggested that an arthroscopic-assisted approach combined with use of an external fixator and minimally invasive internal fixation was the optimal treatment for tibial pilon fractures. As External fixation improves fracture alignment, arthroscopy may improve joint surface restoration, and minimally invasive screw fixation can ensure fragment stability (Cetik et al. 2007). Atesok et al. (2011) suggested that arthroscopic-assisted surgical techniques for intra-articular fracture fixation are minimally invasive, have high accuracy, and have been successfully used for the treatment of tibial plateau, tibial intercondylar eminence, tibial pilon, calcaneus, femoral head, glenoid, greater tuberosity, distal clavicle, radial head, coronoid process, distal radius, and scaphoid fractures. The main disadvantages of these techniques are that they are time-consuming and technically demanding, with a long learning curve.

37.4.3 Surgical Technique

With the patient supine, a tourniquet and leg holder are applied, and the knee is flexed at about 30° (Fig. 37.3). A Steinmann pin is inserted in the calcaneus in order to facilitate ankle joint distraction and fracture fragment reduction. Anteromedial and anterolateral

Fig. 37.3 After confirmation of reduction and of correct angular alignment, the external fixator system is secured

portals are created, and ankle arthroscopy is performed. Debridement with evacuation of the hematoma is required to inspect and evaluate the distal articular surface of the tibia.

The second step involves placement of the external fixator, which is usually a hybrid system consisting of a 3/4 ring and a single tube. First, two pairs of wires are placed through the distal tibia with an angle of 90°, approximately 1.5 cm proximal to the joint surface. These wires are placed under direct arthroscopic inspection of the joint with fluoroscopic guidance (Fig. 37.4). During this step, transcalcaneal traction is applied, and reduction of the fragments is obtained through ligamentotaxis. The correct placement of these wires is one of the most critical parts of the procedure. These wires are responsible for the stabilization of the reduced articular fragments and thus for restoration of a congruent articular surface. Using the arthroscope, any displacement of the fragments during passage of the wires can be judged and subsequently avoided. The wires are then

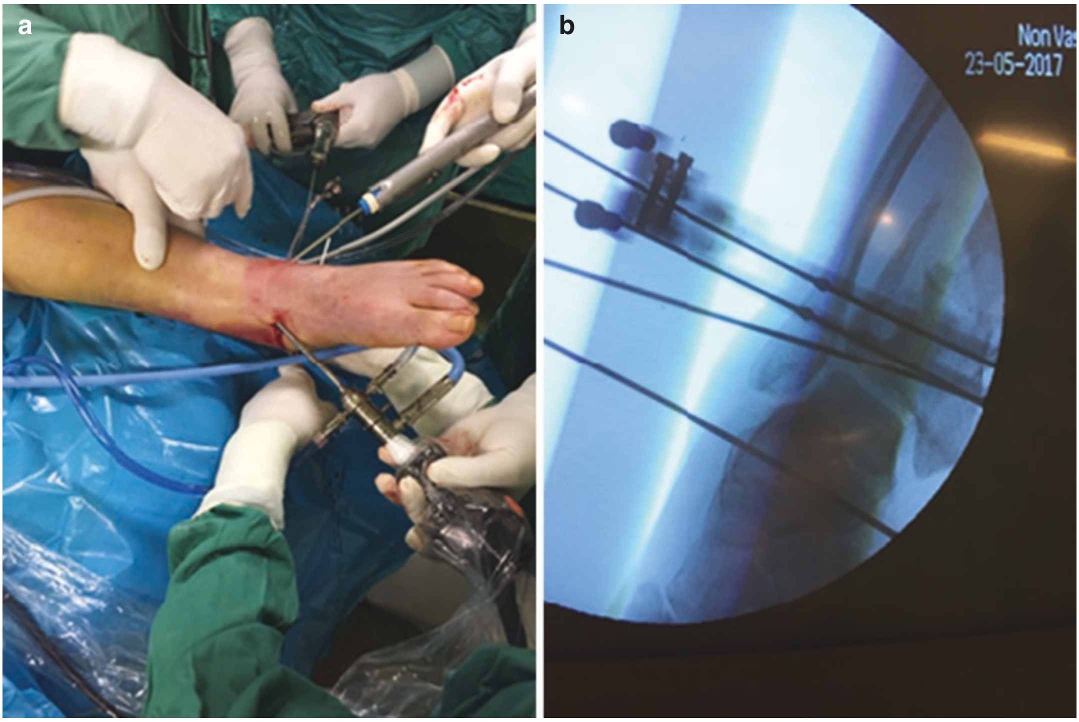

Fig. 37.4 Placement of the distal wires is performed under direct arthroscopic inspection (**a**) and fluoroscopic imaging (**b**)

assembled to the 3/4 ring portion of the fixator. Following this step, two Schanz screws are placed on the anteromedial surface of the tibial diaphysis, and the tubular rod of the fixator is attached to them. Reduction of the metaphyseal part of the fracture is achieved through traction. After confirmation of reduction and of correct angular alignment (using intraoperative fluoroscopy), the external fixator system is secured (Fig. 37.3). Postreduction arthroscopy follows to remove any small fracture fragments and to evaluate the articular surface reduction (Fig. 37.5).

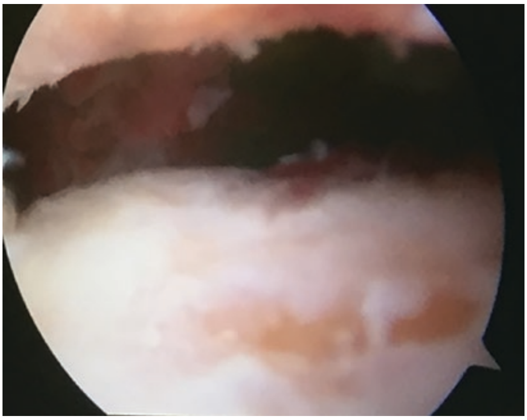

Fig. 37.5 Postreduction arthroscopy follows for a final evaluation of articular surface reduction effectiveness

Postoperative radiographs are obtained after the operation (Fig. 37.6), and patients start active range-of-motion exercises on the second day. Gradually increasing partial weight-bearing is allowed, starting at 6 weeks postoperatively. Once full union is achieved, usually after 10–16 weeks, full weight-bearing is allowed, and 2 weeks later, the external fixator is removed. The main goal of postoperative rehabilitation is to retain full ankle joint range of motion.

37.5 Conclusion

Pilon fracture management is challenging because of involvement of the distal articular surface of the tibia and the complexity of associated soft tissue injuries. Arthroscopic-assisted hybrid

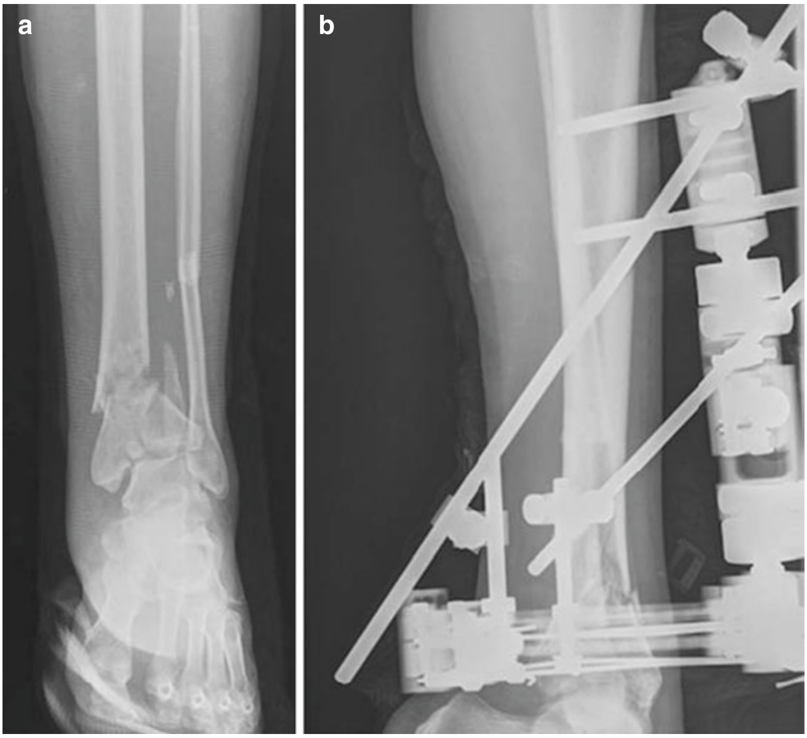

Fig. 37.6 Preoperative anteroposterior (**a**) and postoperative lateral view (**b**) showing successful reduction using external fixation

external fixation combines the advantages of external fixation (decreased soft tissue exposure and early joint mobilization) with an optimal articular reduction through direct arthroscopic inspection.

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Treatment of Tibia Pilon Fractures with the Ilizarov Method

38

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38.1 Introduction

The term pilon fracture was first used in 1911 by French radiologist Destot and comes from the French for pestle. Tibia pilon fracture is a fracture including the metaphysis section at the distal part of the tibia (plafond roof). The tibia plafond forms a roof over the talus bone and has a smooth surface ensuring contact between the distal tibia and the talus. The ankle is formed by the plafond above and by the talus below and by the lateral, medial, and posterior malleoli. In the sagittal plane the plafond is concave, while in the coronal plane it is convex. The anterior section of the plafond is wider to tolerate axial loads.

There is a broad range in terms of surgical treatment for tibia pilon fractures. There are several treatment alternatives, especially for the treatment of high-energy complex pilon fractures. None of these methods can be claimed as gold standard. Infection is commonly observed after internal fixation. McFerran et al. (1992) reported a 54% complication rate in treatment of these types of fractures, while Helfet et al. (1994) reported a complication rate of 70%. The final result is arthrodesis in 26% of patients, with amputation in 16% of patients. Teeny and Wiss (1993) reported complications like pseudoarthrosis, infection, and implant breakage in 50% of 60 patients operated on for tibia pilon fracture. When selecting the fixation method for a tibia pilon fracture, evaluation of the soft tissue condition and fracture fixation quality is important, to prevent complications (Casstevens et al. 2012; Newman et al. 2011). These complications are more common with high-energy trauma (Mauffrey et al. 2011). In addition to treatment planning in high-energy trauma, careful monitoring of soft tissue condition, and waiting 7–14 days for reduction of soft tissue edema are necessary to reduce the risk of complications (Yalçın et al. 2007).

Treatment of open fractures is difficult. To decrease complication risk, several methods and combinations have been described like minimally invasive methods, two-stage procedures, unilateral fixator applications, hybrid jointed ankle fixators, and circular Ilizarov external fixator. No matter which method is used, major skin incisions should be avoided (Mauffrey et al. 2011).

A staged protocol is important in treatment of tibia pilon fractures (Boraiah et al. 2010; Wyrsch et al. 1996). To date there is no consensus on the treatment of complications after pilon fractures such as delayed or nonunion and pseudoarthrosis. According to some studies, the infection risk during pilon fracture treatment approaches 55% (Joveniaux et al. 2010; Zelle et al. 2006). Infection risk increases with longer duration of

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the surgical procedures and open fractures (Miller et al. 2012). Hyperglycemia associated with diabetes is an additional serious risk factor for infection (Theuma and Fonseca 2003). This is related to microvascular pathology that creates ischemia in the extremities. These complications have also increased the popularity of external fixation. Until skin creases are clearly seen, patients should rest with leg elevation. Temporary fixator use may enable joint mobilization and thereby assist with edema reduction (Yalçın et al. 2007). A temporary fixator application means that the patient must undergo two surgical procedures, and treatment costs will be higher. Therefore, the ultimate treatment should take place soon after the trauma. The external circular ilizarov fixator enables earlier surgery post-trauma and earlier joint mobilization. Another advantage of the Ilizarov external fixation method is that it allows early ambulation with load bearing (Leung et al. 2004; McDonald et al. 1996).

38.2 Surgical Technique

Fifty-three patients with tibia pilon fractures were treated at our clinic between 2010 and 2014 using the Ilizarov method. The patients included 40 males and 13 females. The mean age was 45.3 years (range = 23–62 years). High-energy trauma such as traffic accidents and falls from a height was involved in more than 80% of the patients. According to AO classification, four fractures were type A1, four were type A2, four were type A3, eight were type B1, five were type B2, seven were type B3, six were type C1, seven were type C2, and eight were type C3. The surgical procedure followed these stages:

1. External ring fixation, according to the fracture shape.
2. Fracture continuity was ensured.
3. Fixation and compression of fracture fragments with reduction and arrangement was ensured using Kirschner (K) wires.

The location of Ilizarov rings was completed according to the fracture type in the AO classification. A type fractures had the Ilizarov apparatus planned and set with three full rings used, B type fractures had two full rings and one half ring, and C type fractures had three full rings and one half ring. Patients were positioned in supine and transcalcaneal traction was applied. Reduction after ligamentotaxis was checked using fluoroscopy.

While applying the three-ring Ilizarov apparatus, K-wires linked to the proximal ring were passed through the proximal metaphysis of the tibia. Wires holding the central ring passed close to the distal part of the proximal fragment of the tibia. Changes in fragment location were noted when placing the wires. Depending on fragment location, they were inserted from inside to outside, or outside to inside, and wires with stops and abutment points were used. The distal ring was joined to the base rings without wires. A wire with an abutment point (stop) was passed from the calcaneus, and the half ring was fixed and tensioned. Diastasis was created at the ankle joint, and fragment displacement was roughly corrected. The remaining fragment displacement was reduced with an awl (Kirschner, hook) “joystick” with 3–4 mm pointed tip and reduced percutaneously under fluoroscopic control. Fragment fixation was completed using 1.8–2.0 mm olive wire. Using the distal tip of the tibia as a reference point, the fragments of the anterior and posterior edges of the ankle joint surface were reduced. It is important that reduction of the tibia plafond forming the ankle joint surface be carefully performed. However, in situations where this may not be possible especially in C type fractures, reduction was attempted after a small incision was made, and the reduced fragments were fixed with olive wires. To prevent supination and drop foot, the foot was fixated with the ankle in neutral alignment. The wire through the calcaneus was generally removed after 1 month (40–45 days for some type C2 and C3 fractures), and ankle movement was allowed.

Patients were not allowed to bear weight until the wire was removed. After the calcaneal wire was removed, ankle movement and partial weight-bearing were allowed. No bone grafts were used. While surgery was completely closed in 43 patients, in 10 patients a small incision was made to ensure reduction.

38.3 Results

Mean union duration was 14.6 months (12–22 months). According to the Mazur's criteria, 39 patients (74%) sustained very good or good results. In ten patients (19%) sufficient results were obtained, while in four patients (7%) the results were poor. Sufficient and good results were recorded for all type A (1, 2, 3) and type B (1, 2) fractures. Poor results were observed for type C2 and type C3 fractures.

No patient developed an infection or deep vein thrombosis. In 11 patients superficial soft tissue infections occurred around the K-wires. This situation was treated with oral antibiotics and dressings. In four out of seven patients with open fracture, skin necrosis was observed after surgery (Fig. 38.1). In all patients wounds healed without complications except for one patient that required a skin graft. More than 80% of the patients had full return of ankle range of motion. Ankle arthrodesis was performed in two patients.

38.4 Discussion

The Ilizarov method is a minimally invasive method allowing fixation of the bone with the aid of K-wires, threaded rods, and a frame (Fig. 38.2). It was described by Gavriil Abramovich Ilizarov at the beginning of the 1950s. It gained global popularity after an Italian reporter was treated with this method. It provides satisfying results for open fractures, pseudoarthrosis, lengthening extremities, and deformities. Among the advantages of this method are that it is minimally invasive, the patient may ambulate with early weight-bearing and may return quickly to normal daily activities, and the apparatus can be adjusted during recovery to maintain ligamentotaxis effects.

Fig. 38.1 Patient who sustained skin necrosis

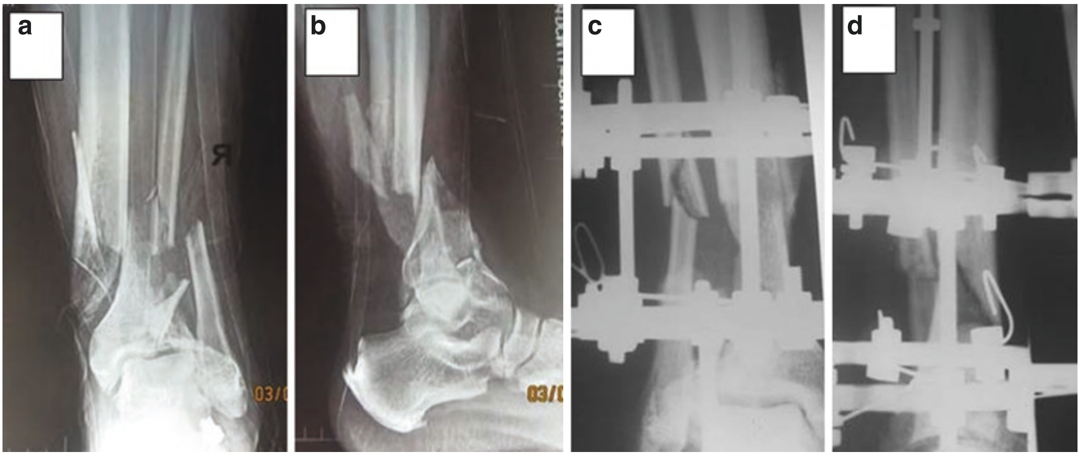

Fig. 38.2 (**a**) Anteroposterior radiograph before operation, (**b**) lateral radiograph before operation, (**c**) anteroposterior radiograph after operation, (**d**) lateral radiograph after operation

For a more stable fixation with the Ilizarov method, three or four rings may be used. If the fracture is closer than 3–4 cm from the joint level, a fourth ring may be used as a foot ring for more stable fixation including the foot. To shorten the surgery duration, planning should be made before surgery, and the rings preassembled. The rings should be perpendicular to the mechanical axis and parallel to each other. Full rings created by joining two half rings should be placed at least 2 cm from the skin. The Ilizarov frame should be at least 2 cm from the skin to reduce pressure on the skin from the frame if edema develops in the extremity and to reduce the necrosis risk. In practice, a distance of two fingers between the frame and skin should be sufficient. However, leaving more space between the frame and the skin to reduce this risk may cause a biomechanically weaker fixation. Leaving four rods between the rings ensures better fixation. Carbon rings should be used to be able to evaluate joint congruency on postoperative radiographs.

If the fracture line is closer than 3–4 cm to the joint level, the foot should be included in the frame for more stable fixation. When including the foot within the Ilizarov system, care should be taken that it not be placed in a drop foot position (Dağlar 2016).

Another advantage of Ilizarov external fixator is ligamentotaxis (Bone et al. 1993; Lovisetti et al. 2009). Ligamentotaxis is an important factor in functional healing of fractures. However, the necessity of including the ankle may be considered a disadvantage (Mauffrey et al. 2011). Foot fixation does not always result in decreased ankle movement. Okcu and Aktuğlu (2004) stated that external fixator use ensured better ankle movement. Additionally, there are reports stating that external fixator application provides worse results in terms of post-traumatic arthrosis (White et al. 2010), while there are also reports stating that it makes no difference (Davidovitch et al. 2011). To prevent limited subtalar joint movement, it is recommended that wires passing through the ankle joint bypass the talus (Fırat et al. 2013). Another advantage of the Ilizarov system is that it allows stable fixation in osteoporotic bone.

While threaded rods may be used for fixation of the frame proximal to the fracture line, for distal ring fixation at the distal tibia, we may use K-wire and reduction (olive) wires. The threaded rods should be inserted 90 degrees perpendicular to each other. Kirschner (K) wires should be inserted into the distal tibia at a minimum of 60 degrees apart (Aktuğlu and Özkayın 2013). Fracture fragment reduction may be easier with olive wires (Yalçın et al. 2007). With ligamentotaxis, unreduced fragments may be reduced with a pointed awl or K-wire “joystick.” The surgical procedure should be performed on large bone fragments (Mauffrey et al. 2011). Tension on the wires reduces the infection risk.

While infection is a risk of every surgery, Ilizarov apparatus application especially for high-energy trauma reduces this risk (Yalçın et al. 2007). The risk of deep infection is lower compared with open surgery. The complication incidence rate in patients with internal osteosynthesis may approach 70% (Helfet et al. 1994). A comparative prospective randomized study of internal osteosynthesis and external osteosynthesis by Wyrsch et al. (1996) reported lower complication rates in the group with external osteosynthesis. Research by El-Mowafi et al. (2015) stated that Ilizarov apparatus external fixator use reduced the need for a large surgical incision and was a useful method for pilon fracture treatment.

In retrospective research, Okcu and Aktuğlu (2004) reported that patients treated with the Ilizarov method had better ankle joint mobility than after open fixation. Fırat et al. (2013) showed that hinged Ilizarov external fixator use was an effective treatment method for tibia pilon fractures.

Pilon fracture treatment complication rates are high (Helfet et al. 1994). While choosing the fixation method, it is important to take note of complication risks linked to the soft tissue condition (Casstevens et al. 2012; Newman et al. 2011).

Complication rates tend to be lower with treatment methods involving external fixators (Wyrsch et al. 1996). However, results may be worse for multifragmented pilon fracture cases, especially with central collapse. As fragments with no link to soft tissue cannot be reduced with ligamentotaxis, they may require fixation with minimally invasive methods (Yalçın et al. 2007). In these types of cases, additional fixation with percutaneous cannula screws and grafting may provide better results (Ersan et al. 2005). Early ankle mobilization may prevent Sudeck's atrophy and may improve cartilage healing (Ersan et al. 2005). Following external fixation, minimally invasive plates are useful to enable early ankle movement. However, it should not be forgotten that good results strictly with external fixator use have been reported (Aktuğlu and Özkayın 2013; Pavolini et al. 2000; Vidyadhara and Rao 2006).

Factors that limit the use of the Ilizarov apparatus method are the difficulty in using the device and complications related to its external presence. While reduction of fractures with ligamentotaxis is the aim of using external fixators, it is difficult to ensure full repositioning of multifragmented fractures of the distal joint surface of the tibia (Bone et al. 1993; Lovisetti et al. 2009). For better reduction of the fracture line, it may be helpful to use arthroscopically assisted minimally invasive methods (Fischer et al. 1991). Opinions differ in terms of two-stage surgery (Aktuğlu and Özkayın 2013; Pugh et al. 1999; Sirkin et al. 1999).

38.5 Conclusion

The Ilizarov apparatus should be applied according to the AO classification of fractures of the tibial distal epiphysis. For closed reduction with ligamentotaxis of fragments in distal tibial epiphysis fractures, fixation should be performed with wires. In the presence of multifragmented displaced fractures, a pointed awl allows percutaneous fragment reduction without the need to open the fracture. Percutaneous Ilizarov system use does not disrupt endosteal and periosteal nutrition, and fragments may be compressed with olive wires (Vidyadhara and Rao 2006). When closed reduction is not possible, reduction may be performed using a small incision and olive wire fixation.

Treatment of pilon fractures with a circular external fixator without internal fixation (in accordance with Ilizarov principles) appears to require less soft tissue dissection. The Ilizarov external fixator system is a reliable method for treatment of fragmented pilon fractures with low complication rates.

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Malleolar Fractures: Guidelines and Tips for Surgical Fixation

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39.1 Introduction

The ankle joint is the most commonly injured weight-bearing joint in the human body. A spectrum of injuries is possible from stable simple soft tissue injuries to unstable, complex open ankle fractures or fracture dislocations. These fractures, which demonstrate bimodal age distribution, are generally related to low-energy injuries (Court-Brown et al. 1998; Michelson 2003).

The saddle-shaped, modified hinge-type ankle joint is located between the distal fibula, distal tibia, and talus. The stability of the joint mainly depends on the bony articulation of these structures, lateral and medial supporting ligaments (mainly the deltoid ligament), and tibiofibular syndesmosis (Davidovitch and Egol 2009; Michelson 2003; Ogilvie-Harris et al. 1994; Tornetta III 2000). In neutral position, 90% and 10% of the load is transmitted through the tibial plafond and lateral talofibular articulation, respectively (Michelson 2003). The relative lack of soft tissue coverage is often related to complications. Ankle joint function depends on maintenance of the normal anatomical ankle mortise relationship and syndesmotic integrity.

The diagnosis of malleolar fracture is usually established on plain radiographs (Lesic and Bumbasirevic 2004). Three-dimensional computed tomography (CT) and magnetic resonance imaging (MRI) are useful for high-energy injuries and for detection of ligament, tendon, or chondral injuries, respectively (Lesic and Bumbasirevic

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2004). Below are the classifications of ankle fractures:

- According to the level of fibula fracture:
  - Danis-Weber classification system
    Type A: at a level distal to tibial plafond
    Type B: at the level of tibiofibular joint
    Type C: proximal to the level of tibiofibular joint
  - AO/OTA classification system—44 (Ruedi et al. 2007)
    Types A, B, and C, the same as the Danis-Weber classification
- According to the position of the foot and direction of the deforming force:
  - Lauge-Hansen classification system (Lauge-Hansen 1950; Lauge-Hansen 1953)
    Supination—external rotation
    Supination—adduction
    Pronation—external rotation
    Pronation—abduction
    Pronation—dorsiflexion

The most common ankle joint fracture patterns are lateral malleolar, bimalleolar (including its equivalent with deltoid ligament rupture as in the supination-external rotation Lauge-Hansen classification type), and trimalleolar fractures. Malleolar fracture management can be summarized into three general approaches: nonsurgical, staged, and surgical (Yufit and Seligson 2010). In general, stable and unstable ankle fractures can be managed nonsurgically or surgically, respectively. Staged treatment with external fixation and delayed internal fixation is reserved for high-energy fractures/fracture dislocations with compromised surrounding soft tissues (Michelson 2003; Yufit and Seligson 2010).

Although there is a growing trend toward surgical malleolar fracture management, this is often not an easy decision. Decision-making considerations include the exact fracture type classification, syndesmosis stability, ability to restore the distal fibula to its premorbid length without malrotation, and whether or not the posterior malleolus will require surgical stabilization. Moreover, considerations must include the medial osteoligamentous complex integrity and the medical condition of the patient, including comorbidities, such as diabetes, osteoporosis, or obesity (Michelson 2003; Wendsche and Drac 2012; Yufit and Seligson 2010). As malunion is probably the most important factor in the development of post-traumatic ankle osteoarthritis, anatomical reduction, stable internal fixation, and appropriate postoperative care are of utmost importance to maximize patient function and minimize short- and long-term complications. Interestingly, close contact casting has been shown to provide a clinically equivalent outcome to open reduction internal fixation (ORIF) at a reduced cost at 6 months after fracture treatment in patients over 60 years of age (Keene et al. 2016).

Although evidence-based consensus is still lacking, more than 80% of these fractures are managed with surgical methods (Koslowsky et al. 2007; Mendelhall 1998; Reinherz et al. 1991). In general, malleolar fractures are treated surgically using ORIF. General rules related to malleolar fracture management have been summarized in previous studies (Lesic and Bumbasirevic 2004; Nuney 1999; Pugh 2002). A useful stepwise malleolar fracture fixation method was described by Yufit and Seligson (2010).

1. Explore the medial side and achieve provisional medial malleolus fixation.
2. Restore fibular length and rotation, followed by lateral malleolus fixation.
3. Assess and stabilize the ankle syndesmosis, if necessary.
4. Achieve medial malleolus and/or posterior malleolus fixation as needed.

A systematic review reported the results of 1822 surgically treated malleolar fractures (Stufkens et al. 2011). They found that approximately 80% of optimally reduced fractures showed good to excellent long-term outcomes and that poor fracture reduction resulted in inferior long-term outcomes compared with fair to good reduction. The same study revealed that Danis-Weber type A fractures do not have a better long-term outcome than type B fractures and that Lauge-Hansen supination-external rotation grade 2 fractures did not have a superior long-term outcome compared with supination-external rotation grade 4 fractures. Two important implications were the necessity to identify risk factors such as smoking, diabetes, osteoporosis, and obesity and that no relevant conclusions can be drawn from the currently available literature, in terms of other factors such as articular cartilage lesions, posterior malleolus, and hindfoot alignment.

Ankle fractures that include a posterior malleolar fragment (trimalleolar fractures) have worse prognosis than bimalleolar fractures (De Vries et al. 2005). Moreover, outcomes of bimalleolar fractures are poorer than those of lateral malleolar fractures with medial deltoid ligamentous injury (Tejwani et al. 2007). Pronation or Danis-Weber type C malleolar fractures are associated with poorer outcome scores (Lesic and Bumbasirevic 2004).

This chapter presents guidelines and tips for the surgical management of ankle malleolus fractures (lateral, medial, posterior), including comparison of a variety of surgical fixation methods. The technical details related to syndesmosis fixation and medial and lateral ligamentous repair or reconstruction are out of scope of this chapter.

39.2 Malleolar Fractures

There are three ankle malleoli: medial, lateral, and posterior. A fracture may be isolated or combined as bimalleolar/trimalleolar or a fracture-dislocation.

39.2.1 Lateral Malleolar Fractures

Two well-known studies have emphasized the importance of the lateral malleolus as to reduce the risk of lateral talar displacement and as a vital stabilizing structure (Ramsey and Hamilton 1976; Yablon et al. 1977). The study of Thordarson et al. (1997) further demonstrated that fibular displacement more than 2 mm created significant contact pressure reduction at the tibiotalar joint. Lateral malleolar fractures of Danis-Weber or AO/OTA type B (trans-syndesmotic) are the most frequently encountered ankle fractures (Court-Brown et al. 1998; Court-Brown and Caesar 2006). Various surgical fixation methods have been described (Table 39.1), but the best method is still to be determined. The two main lateral malleolar fracture fixation categories are plating and intramedullary fixation.

The most frequently used type of lateral malleolar fracture fixation involves lag screw insertion over the fracture site and the use of a neutralization plate, such as a one-third tubular or anatomical distal fibular plate (Sanders et al. 2012). In terms of type of plate, Tsukada et al. (2013) failed to identify any clinical and radiological differences between patients with AO/OTA type B lateral malleolar fractures, who underwent fixation with a locking versus a non-locking neutralization plates. Locking compression plates have advantages of safer treatment of osteoporotic and comminuted fractures, greater stability, stronger torque, easy operative application, superior periosteum protection, possible use of several distal fragment locking screws, having a lower hardware profile, and enabling earlier rehabilitation than standard stainless steel plates (Freeman et al. 2010; Frigg 2003; Miersch et al. 2011; Yeo et al. 2015; Zahn et al. 2012).

Sakai et al. (2017) demonstrated in their comparative biomechanical study that structurally modified plates with distal hooks did not make

Table 39.1 Fixation methods for lateral malleolar fractures

• Plates
– One-third tubular plate
– Antiglide plate
– Hook plate
– Conventional/locking compression plate (LCP)
• Intramedullary fixation
– Fibular nail
– Knowles pin
– Rush rod
– Screw
• Tension-band wiring
• Screw only
• Others
– Suture anchor
– Bioabsorbable implants

any difference in repair stiffness. A one-third hooked tubular plate with lag screws, one-third tubular plate with lag screws but without a hook, and LCP provided equivalent stiffness to that of healthy bone. The same study clarified that lag screws inhibited displacement. Others, however, have reported successful clinical results using curved hook plates (Hirakawa et al. 2016; Ikuta et al. 2006).

Gu et al. (2014) reported that in providing a more rigid stabilization, dual plate fixation had a lower complication rate in patients with a comminuted distal fibula fracture. Additionally, bicortical screw placement in the distal fibula was found to be technically feasible and biomechanically stronger than unicortical fixation in a cadaveric, biomechanical study (Milner et al. 2007).

In terms of where to place the plate in Danis-Weber type B fractures, it can be placed lateral or posterolateral/posterior to the distal fibula. The relative advantages of posterior so-called "antiglide" plating include improved biomechanical stability, less soft tissue damage, less hardware prominence, and no risk of distal screw joint penetration (Minihane et al. 2006; Ostrum 1996; Schaffer and Manoli 1987; Treadwell and Fallat 1993; Winkler et al. 1990). Since first described for clinical use (Brunner and Weber 1982), the antiglide plate technique has displayed similar clinical results to other fixation methods without any differences in terms of surgical time, complication, or hardware removal rates (Lamontagne et al. 2002). A percutaneous surgical approach has not been found to be superior compared with open approach for distal fibula fractures (Hess and Sommer 2011).

Since the end of the 1990s, intramedullary fibular nailing using percutaneous technique is another evolving technique (François et al. 1998; Kara et al. 1999; Kabukcuoglu et al. 2000; Rajeev et al. 2011). In the comparative study of Asloum et al. (2014), plate fixation had higher complication rates and lower functional scores than intramedullary nailing, with no differences in union rate. Similarly, Rehman et al. (2015) in a meta-analysis reported that intramedullary fixation yielded lower risk of wound infection, less symptomatic hardware, and less need for hardware removal. Fibular nailing also produced successful results in patients with unstable ankle fractures (Bugler et al. 2012). Newer designs include syndesmotic screw fixation with promising clinical results (Bugler et al. 2012). Arthroscopic assistance may be especially useful in diabetic patients with high risk of wound infection (Thevendran and Young 2012). It should be remembered that the main limitation of intramedullary nail use is a comminuted fibula fracture.

A screw can also be used for the reduction and intramedullary fixation of fibula fractures. Screw fixation has the advantage of safety, decreased cost, faster surgery time, simplicity, no risk of joint penetration, and less risk of soft tissue or neurological complications compared with intramedullary nails and plates (Bankston et al. 1994; Evans et al. 2010; Latif et al. 2013; Lee et al. 2010; Loukachov et al. 2017; Redfern et al. 2003; Rehman et al. 2015; White et al. 2016).

Good results have also been reported with the use of Knowles pin fixation for isolated displaced lateral malleolar fracture (Lee et al. 2005). Advantages include the ease of application, less soft tissue dissection, less implant prominence, stable fixation, shorter operation time, and low complication rates, as demonstrated in a comparative study with plating in open AO-type B2 lateral malleolar fractures (Lee and Chen 2009).

Compression osteosynthesis with figure-of-eight tension-band wiring was initially reported by Sudmann (1974). The compression cerclage system was found to provide good functional and radiological outcomes in patients with lateral malleolar fractures (Cansu et al. 2016). The reported advantages include safe usage, minimal prominent hardware, and minimal soft tissue stripping. These advantages are especially important in patients with a high wound complication risk, such as indivitual with diabetics. Both plating and tension-band wiring have shown excellent clinical and radiological results for the treatment of isolated Danis-Weber type A and type B fractures in a comparative study (Isik et al. 2013).

Although the typical lateral malleolus fixation method is plate osteosynthesis with or without the use of a lag screw, lag screw only fixation has been found to be a safe and effective method of fixation in non-comminuted oblique fractures (McKenna et al. 2007). Advantages associated with this fixation method include limited soft tissue dissection, less prominent hardware, and a reduced requirement for secondary hardware removal (McKenna et al. 2007). Successful clinical results have also been reported with the use of bioabsorbable screws (Handolin et al. 2005a, b).

The randomized, multicenter study of Sanders et al. (2012) reported that patients with non-displaced, unstable, isolated lateral malleolar fractures, who were managed operatively, had similar functional outcomes compared with nonoperative treatment. However, those managed surgically had a lower risk of fracture displacement and nonunion. In a biomechanical study, Deml et al. (2017) reported that isolated lateral malleolar fractures with a fracture gap up to 3 mm were not associated with a change of tibiotalar joint load distribution in vivo. Based on this finding, they suggested that isolated minimally displaced lateral malleolar fractures might achieve good clinical long-term results after nonsurgical management.

Fibula fracture reduction to achieve original length can be performed relatively easily in non-comminuted cases. Various techniques have been developed to make fracture reduction easier, such as the use of a pointed reduction clamp, arthroscopic assistance, or distraction technique (Fitzpatrick and Kwon 2014; Thevendran and Young 2012; Verheyen 2006).

A prospective, randomized study by Takao et al. (2004) demonstrated that osteochondral talus lesions and tibiofibular syndesmosis disruption were present in approximately 73% and 80% of patients with acute distal fibula fractures, respectively. The authors emphasized that exact diagnosis (with arthroscopic assistance) and treatment of the combined intra-articular injury are of great importance in order to achieve satisfactory clinical results.

The main neural and tendinous structures which are at risk during both open and minimally invasive fibula fracture surgical approaches are the superficial peroneal nerve, its branches, and the peroneal tendons (Ahn et al. 2016; Gonzalez et al. 2017; Mirza et al. 2010). In a cadaveric study, it was demonstrated that the superficial peroneal nerve has varied exit point locations through the lateral compartment crural fascia, with an average location of 11.6 cm proximal from the tip of the lateral malleolus.

Gonzalez et al. (2017) reported that a minimally invasive percutaneous surgical approach to distal fibula fracture management produced similar radiological and functional outcomes, compared with an open approach. Although neural damage is relatively infrequent following ankle fractures, superficial peroneal nerve and nerve branch injuries may lead to significant morbidity (Halm and Schepers 2012). Protection of these structures can reduce the incidence of neurological injuries, especially the Blair-Botte type B intermediate cutaneous dorsal nerve branch, which occurs in 10–15% of patients. When present, this branch crosses the distal fibula from posterior to anterior at 5–7 cm proximal to the malleolar tip. Clinically evident peroneal tendinopathy after the use of posterior antiglide plating has been reported to be higher than after lateral plating (Choi et al. 2007). However, it has recently been reported to be as low as 4% (Ahn et al. 2016).

It is important to remember that additional surgery for symptomatic implants is required for up to one-third of operated ankle fractures (Loukachov et al. 2017; Pot et al. 2011). Brown et al. (2001) reported that ankle pain after surgical fixation of lateral malleolar fracture and after hardware removal was present in 31–50% of cases.

39.2.2 Medial Malleolar Fractures

Medial malleolar fractures are encountered as isolated fractures or as a component of bimalleolar or trimalleolar fractures. Apart from the aforementioned classifications of malleolar fractures, isolated medial malleolar fractures are further classified according to fracture geometry (Ebraheim et al. 2014; Herscovici et al. 2007).

The aim of medial malleolar fracture treatment is to prevent post-traumatic osteoarthritis, non-union, malunion, and instability by achieving anatomical fracture reduction (Kusnezov et al. 2017). Anatomical reduction and stable fixation are important in order to restore ankle mortise laxity (Michelson et al. 1990). Moreover, anatomical fixation is vital for healthy bony union and for the early ankle motion, which has been shown to improve articular cartilage healing (Mandracchia et al. 1999; Michelson 1995; Mont et al. 1992; Pettrone et al. 1983; Reinherz et al. 1991; Salter et al. 1980).

The classical indications of nonoperative treatment include non- or minimally (≤ 2 mm) displaced fractures, avulsion fractures, compromised soft tissues, and severe medical comorbidity (Hoelsbrekken et al. 2013). Good functional outcomes led Herscovici et al. (2007) to recommend nonsurgical treatment for of minimally displaced fracture cases. However, surgical management is generally advocated for displaced fractures, which may contribute to excessive talar tilt and ankle instability. Although controversy exists when it comes to surgical versus nonsurgical approach, surgical management has been favored more than 40 years (Davidovitch and Egol 2009; Kosuge et al. 2010; Kusnezov et al. 2017; Michelson 1995). However, non-unions, malunions, and increased joint contact pressures due to decreased joint surface area occur with higher frequency after nonsurgical treatment (Ansari et al. 2011; Lareau et al. 2015). In a randomized, comparative study by Hoelsbrekken et al. (2013), non-union at a median follow-up of 39 months was not found to be clinically or functionally significant. Based on these findings, they recommended nonsurgical treatment for patients with severe soft tissue injuries. Moreover, long-term follow-up study by Wei et al. (1999) challenged classical indications for surgery and recommended a focused reconsideration of the decision-making process. The current indication for surgical treatment of medial malleolar fractures is residual displacement of the medial malleolar fragment after fixation of the fibula and syndesmosis in young, active, high-demand, and otherwise healthy patients without any major soft tissue problems (Kusnezov et al. 2017).

In terms of the surgical exposure, both open and percutaneous approaches are used. In a recent study by Saini et al. (2014), a mini-arthrotomy-assisted percutaneous approach, in which the incision is made centered over the superomedial angle of the ankle mortise, about 0.5 cm medial to tibialis anterior tendon, was advised in displaced fractures to enable direct visualization and exact reduction, removal of entrapped soft tissue, and preservation of the saphenous vein and nerves.

Weinraub et al. (2017) identified another important issue related to malleolar fracture surgical approach. They reported that percutaneous fixation led to an increased risk of unhealed fractures at short-term follow-up. Although a percutaneous approach has the advantages of avoiding excessive soft tissue dissection, it has the potential to lead to inadequate, poor anatomical reduction and inaccurate fixation. Tornetta III (2000) reported that having a medial malleolar fragment size of >2.7 cm was critical to achieving fracture reduction that could restore deltoid ligament function. There are various methods of fixation for the surgical treatment of medial malleolar fractures, which were summarized in Table 39.2.

According to the recommendation by the AO Group, the standard conventional techniques for medial malleolus fracture fixation include the use of two 4.0 mm partially threaded cancellous screws with or without washers and tension-band wiring using K-wires for larger and smaller fractures, respectively (Ruedi et al. 2007). To achieve anatomical reduction and adequate fracture site compression screws should be directed at a right ankle to the fracture line, in order. This fixation technique, which is applicable when the fragments are large enough to include two screws, is considered the gold standard for medial malleolar fracture fixation.

Bicortical fully threaded screws, which are placed using the lag screw technique and passed through the lateral tibial cortex, have been found to have superior biomechanical, radiological, and clinical outcomes, compared with traditional partial threaded screw fixation (Ricci et al. 2012).

As the cortex contributes more to bone mechanical and protective functions than cancel-

Table 39.2 Fixation methods for medial malleolar fractures

- Screws
    - – Cancellous/cortical
    - – AO 4.5 mm malleolar screw
    - – Unicortical/bicortical
    - – Partial/fully threaded
    - – With/without washer
    - – Headless cannulated screws
- Plates
    - – Antiglide plate
    - – One-third tubular plate
    - – Contoured mini-fragment T-plate
    - – Hook plate
- Tension-band wiring
    - – Figure-of-eight/knotless
- Kirschner (K) wires
    - – Standard/fine-threaded
- Others
    - – Suture anchor
    - – Staplers
    - – Bioabsorbable screws/pins
    - – Sled device
    - – 3D-printed model of patient's medial malleolus

lous bone, Kupcha and Pappas (2008) described a new technique to fix a medial malleolar fracture, which provides bicortical fracture fixation using shorter cancellous or cortical screws passing through the medial tibial cortex. They suggested that this surgical technique would be advised for patients with a transverse fracture with osteoporotic bone.

The anatomical study of Fermino et al. (2007) demonstrated that screws placed in the anterior colliculus and intercollicular groove of the medial malleolus were less likely to damage the tibialis posterior tendon. Small fragments may sometimes be a real challenge. If the fragment is too small to hold two screws, a 4.0 cancellous screw can be combined with a K-wire, which provides rotational stability. Smaller fragments are usually fixed with two K-wires and a tension-band technique (Fowler et al. 2011; Georgiadis and White 1995; Johnson and Davlin 1993; Ostrum and Litsky 1992). In a comparative cadaveric study of the relative strength of tension-band fixation versus cancellous screw fixation, tension-band fixation was found to be biomechanically superior to screw fixation (Johnson and Fallat 1997). In the same study, tension-band fixation with K-wires was shown to have the following advantages: easy application, flexibility, and decreased fragment comminution risk.

Clyde et al. (2013) described the biomechanical properties of a knotless tension-band construct that displayed greater stiffness and failure strength than conventional screws in a synthetic bone model. Threaded K-wires can withstand equivalent failure force as partially threaded cancellous screws under axial loading conditions in this model (Rovinsky et al. 2000). Successful clinical results have also been reported suggesting that the use of fine-threaded K-wires produced an "auto-compression" effect that maintained fracture fixation and facilitated bone healing (Gausepohl et al. 2001; Koslowsky et al. 2007).

In a limited number of patients with Herzovici type B fractures, Tekin et al. (2016) reported that anterograde headless cannulated screw fixation yielded good clinical results at a mean follow-up of 17 months. Barnes et al. (2014) reported that headless compression screws provided effective medial malleolar fracture compression, providing a useful alternative to the conventional fracture fixation methods (Barnes et al. 2014). Alternatively, a contoured medial malleolus 2.0 mini-fragment T-plate was found to provide a useful alternative to the tension band, by allowing fixation of small fragments that may not be accessible by classical screw configuration (Amanatullah and Wolinsky 2010). Amanatullah and Wolinsky (2010) suggested that advantages associated with the use of this plate included its small size that enabled fragment shape contouring and its low profile. The 2.4 mm cortical screws inserted through the plate made it also function as a washer helping to avoid further fragment splitting by providing compression stabilization. Lastly, the heads of the screws helped prevent penetration in osteoporotic bone.

In Herzovici type C vertical fractures, a neutralization plate and screw fixation have been reported as advantageous in comparative biomechanical and clinical studies (Dumigan et al. 2006; Toolan et al. 1994). However, the use of a 3.5 mm one-third tubular plate was found to be inferior in terms of load to failure, compared with fixation with cortical or cancellous screws (Toolan et al. 1994). It should be emphasized that plating necessitates a larger fragment so that the screw of the plate holds the bone sufficiently. Alternatively, a hook plate has been used mostly for lateral malleolar fractures in order to hold the large fragment for sufficient fixation (Heim and Niederhauser 2007; Zhenhua et al. 2013). Chung et al. (2015) described a precontoured hook plate, prepared according to the real-size 3D-printed model of the patient's medial malleolus. Since this would enable the use of mini-open fixation without the need for large exposures, it has been suggested that this technique may be advantageous in patients with osteoporotic bone and diabetes.

Although titanium staplers can be used in medial malleolar fractures that do not involve the anterior rim, they are not frequently used in current practice (Schiedts et al. 1997). A newly designed sled device yielded similar clinical successful results as conventional screws in terms of fracture union and complications (Maniar et al. 2017).

Biodegradable implants provide another alternative to standard fixation methods; however, their stability is less effective compared with metallic implants (Bostman et al. 1987; Bucholz et al. 1994; Mandracchia et al. 1999). Moreover, the increased risk of an inflammatory reaction related to the use of these implants should be taken into consideration (Hovis and Bucholz 1997). For medial malleolar avulsion fractures with traumatic dislocation of the posterior tibial tendon, good clinical results have been reported with the use of a new surgical technique combining suture anchor use with quadrilateral periosteal flap coverage (Jeong et al. 2015).

Ebraheim et al. (2014) reported a treatment algorithm useful for medial malleolar fracture management according to his newly described so-called "geometric" classification system. In summary, this study stated three important points. Firstly, both tension band and lag screws resulted in similar transverse fracture union rates. However, tension-band constructs were associated with less need for revision surgery and fewer complications. Secondly, oblique fractures were most effectively treated with lag screws. Lastly, vertical fractures had better clinical outcomes with buttress plating.

39.2.3 Posterior Malleolar Fractures

The posterior malleolus has important contributions to ankle mortise and syndesmosis stability (Gardner et al. 2006; Veltman et al. 2016). Isolated posterior malleolar fractures are relatively rare compared with lateral and medial malleolar fractures (Boggs 1986). They are commonly encountered together with fractures of the other malleoli, creating a so-called trimalleolar fracture. During parachute landing, this has been described as "paratrooper's ankle fracture" (Young et al. 2015). Their incidence has been reported to represent between 7% and 44% of all ankle fractures (Irwin et al. 2013).

Posterior malleolar fractures have been classified into three types by Haraguchi et al. (2006) by using computed tomography, as the most common type being the posterolateral oblique type:

- Posterolateral oblique
- Medial extension
- Small shell

Fragment size mainly guides the current malleolar fracture management strategies (Lesic and Bumbasirevic 2004; Macko et al. 1991; Michelson 2003; Veltman et al. 2016). In most cases the posterior-inferior tibiofibular ligament is intact, and if the fracture fragment is small, it can be reduced to an acceptable position through ligamentotaxis as the lateral malleolus is reduced (Lesic and Bumbasirevic 2004; Michelson 2003). The surgical treatment aims to reconstruct the posterior tibial plafond, the fibular notch, and the integrity of posterior-inferior tibiofibular ligament (Bartonicek et al. 2017).

In contrast to well-established management of lateral and medial malleolar fractures, the management of posterior malleolar fractures is still controversial. Although there is generally agreement related to the decision for the surgical treatment for posterior malleolar fractures, with a fragment size of >25–33% of the distal tibial plafond and displacement over 2 mm, this consensus has been challenged by recent studies (Bartonicek et al. 2017; Odak et al. 2016; Tenenbaum et al. 2017; Veltman et al. 2016). These studies also emphasized that surgical treatment should focus not only on fragment size but also on ankle joint structural integrity, presence of fracture dislocation at injury, articular surface integrity, involvement of the fibular notch, presence of intercalary fragments, and residual talar subluxation. All of these factors have an important impact on the prognosis.

In terms of reduction and fixation techniques, direct (posterolateral/posteromedial) and indirect methods are possible. Recent studies have demonstrated that direct open reduction and internal fixation with plate or screws using a posterolateral approach is biomechanically more stable than indirect reduction by ligamentotaxis and fixation with anteroposterior/posteroanterior percutaneous screw (Abdelgawad et al. 2011; Bartonicek et al. 2017; Gardner et al. 2011). An indirect reduction technique has disadvantages associated with increased risk of scarring, tendon impingement, and sural nerve injury (Choi et al. 2015; Gonzalez et al. 2015). In a recent study, the direct reduction technique provided better fracture reduction quality and functional outcomes, especially in the management of posterior malleolar fractures that affected over 25% of the articular surface (Shi et al. 2017). Alternative surgical approaches include combined fixation of medial and posterior malleolar fractures, a modified transmalleolar approach for complex trimalleolar fractures, and reduction techniques using K-wires as “joysticks” to relocate displaced fractures have also been reported (Karachalios et al. 2001; Lee et al. 2009; Mizel and Temple 2004; Strenge and Idusuyi 2006). Alternatively, successful clinical results at a mean follow-up of 24 months have also been achieved with the use of a suspension device (TightRope, Arthrex) in a limited number of patients with posterior malleolar fractures.

39.3 The Use of Arthroscopy in Malleolar Fractures

As the importance of minimally invasive fracture surgery has increased in order to minimize complications such as non-union and soft tissue injuries, the concordant evolution of the use of arthroscopy in “joint-related fracture” surgery has developed (Atesok et al. 2011; Bonasia et al. 2011; Chan and Lui 2016; Hepple and Guha 2013). The main advantages of arthroscopically assisted fracture fixation are summarized as superior joint surface visualization, minimal invasiveness, improved fracture reduction and fixation accuracy, better clinical outcomes and diagnosis, and simultaneous repair of associated intra-articular osteochondral ligamentous and syndesmotic injuries (Atesok et al. 2011; Bonasia et al. 2011). The disadvantages can be summarized as increased surgical time, greater surgical technical demands, prolonged learning curve, overlapping subspecialties, limited fixation alternatives, and risk of soft tissue swelling (Atesok et al. 2011; Bonasia et al. 2011). Severe soft tissue compromise is a relative contraindication to the use of arthroscopy for malleolar fractures (Bonasia et al. 2011). Particular attention should always be given to maintain adequate fluid outflow from the joint during arthroscopic-assisted fracture fixation.

There is growing evidence, less than ideal outcomes and residual symptoms after ORIF for malleolar fractures in association with a high rate of untreated concomitant intra-articular lesions (Bonasia et al. 2011; Leontaritis et al. 2009; Ono et al. 2004). Although Amendola et al. (1996) demonstrated that arthroscopic debridement of well-reduced malleolar fractures with chronic pain was ameliorative clinically, the simultaneous use of arthroscopic-assisted fracture fixation allows for anatomical fracture reduction confirmation and simultaneous, prompt treatment of intra-articular lesions. This approach is important in order to prevent or minimize long-term complications such as malunion, persistent ankle pain, and ankle osteoarthritis (Porter et al. 2008; Ramsey and Hamilton 1976; Specchiulli and Mangialardi 2004). Ankle arthroscopy is

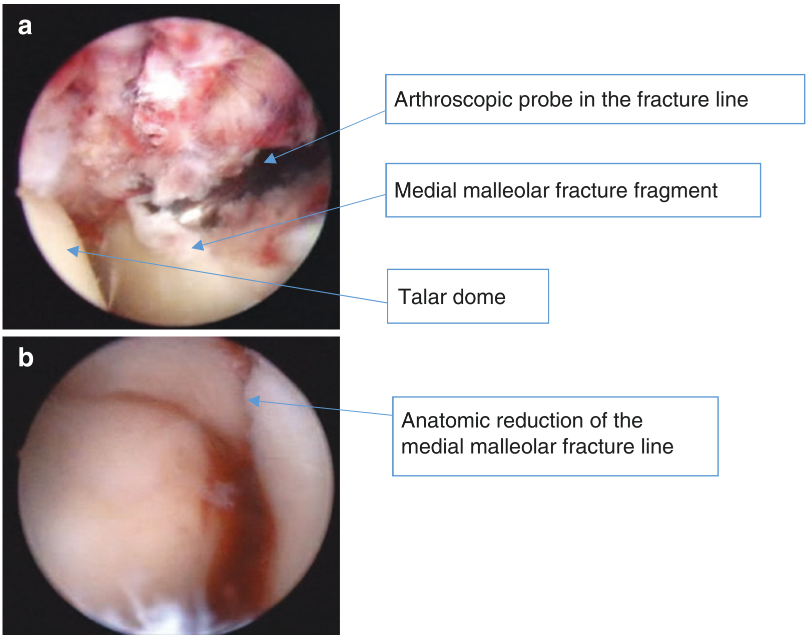

Fig. 39.1 Arthroscopic view of a medial malleolar fracture, with the arthroscopic probe in the fracture line (**a**). After meticulous "debridement" and fracture fixation (**b**). Note the arthroscopic view of anatomic reduction and fracture compression

currently accepted as a useful tool to understand the severity and complexity of acute malleolar fractures (Chan and Lui 2016).

Turhan et al. (2013) demonstrated that the use of arthroscopic-assisted techniques for isolated medial malleolar fracture management enables the surgeon to evaluate the intra-articular surface and to confirm fracture reduction and fixation (Fig. 39.1). Thordarson et al. (2001) found no significant clinical differences between conventional and arthroscopic-assisted approaches for the treatment of distal fibula fractures. The use of an arthroscopic transfibular approach for treating patients with a Danis-Weber type B lateral malleolar fracture has been described as a useful and easy way of removing bone fragments and organized hematoma that block reduction leading to fracture gap development (Noh et al. 2015).

Fuchs et al. (2016) demonstrated that arthroscopic evaluation in patients with an acute ankle fracture did not significantly improve intermediate-term functional outcomes (Fuchs et al. 2016). Braunstein et al. (2016a, b) suggested that the greatest evidance for arthroscopic-assisted treatment of complex ankle fractures compared with conventional ORIF efficay will be known through future randomized controlled studies. The ideal role and effectiveness of arthroscopic-assisted techniques for the surgical management of malleolar fractures still warrants further high level studies with long-term follow-up (Atesok et al. 2011; Bonasia et al. 2011; Braunstein et al. 2016a, b).

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The Role of Arthroscopy in the Management of Fractures Around the Ankle

40

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40.1 Introduction

Ankle fractures are one of the most common fractures (Daly et al. 1987). Newer techniques, focusing on accurate anatomical reduction and stable fixation, result in improved outcome (Ali et al. 1987; Hughes et al. 1979; Yde and Kristensen 1980). However, soft tissue injuries, associated either with the original injury or with surgical treatment, continue to cause problems, like recalcitrant pain, resulting in stiffness, soft tissue damage, residual articular incongruity, which are quite common after appropriate treatment of ankle fractures by open methods (Bauer et al. 1985a, b; Cass et al. 1985). Arthroscopic evaluation allows detailed examination of the articular cartilage, ligaments and other soft tissues for precise reduction and restoration of normal joint architecture and congruity without causing additional vascular and soft tissue damage.

The concept of ankle arthroscopy has been reported in literature for a long time. In 1931, Burman reported his experience with arthroscopy of multiple joints in a cadaver (Burman 1931). According to him, the ankle joint was unsuitable for arthroscopic viewing.

In 1939, Takagi described a method for ankle arthroscopy in Japanese orthopaedic literature (Takagi 1939). In 1981, the first published report of ankle arthroscopy in the American literature was by R. Johnson (Johnson 1981).

Indications (Hinderman et al. 2000; Loren and Ferkel 2002): Fractures amenable to arthroscopic assistance using either a traditional open or a minimally invasive approach include the following:

1. Unimalleolar fractures
2. Bimalleolar fractures
3. Certain minimally displaced trimalleolar fractures
4. Proximal fibula fractures (Maisonneuve fracture)
5. Unstable diastasis/syndesmotic injuries
6. Tillaux fractures
7. Triplane fractures
8. Select pilon fractures
9. Osteochondral talar fractures and select talar body fractures
10. Calcaneus fractures

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Contraindications to using arthroscopic technique include:

1. Grossly compromised soft tissue envelope with massive swelling, blisters, open fracture, neurovascular injury and infection
2. Fracture that is significantly displaced and unstable, like fracture dislocation with or without ligamentous disruption that obviously demands open reduction and internal fixation
3. Advanced degenerative joint disease
4. Chronic lymphatic and vascular insufficiency

Advantages (Bonasia et al. 2011; Turhan et al. 2013)

1. The articular joint surface can be directly inspected and indirectly palpated.
2. Allows for articular cartilage loose bodies to be removed.
3. Enables bone debris and hematoma evacuation.
4. Provides the opportunity to reduce and confirm articular surface alignment and congruency.
5. Allows for a more thorough examination of capsuloligamentous structures.
6. Operative procedures create less soft tissue and vascular damage.
7. Reduces hospitalization time and postoperative morbidity.
8. The procedure is cosmetically more acceptable, and early rehabilitation can be performed.
9. It provides better visualization and management of syndesmotic injuries.

Disadvantages

1. Possibility of neurovascular structure damage
2. Central and posterior talus region instrumentation access difficulty
3. Expensive instrumentation

Complications

1. Compartment syndrome in setting of acute fractures
2. Neurovascular injury
3. Risk of iatrogenic articular cartilage injury from repetitive introduction and removal of instruments
4. Infection

Goal of Arthroscopic-Assisted Fracture Reduction and Fixation

1. To ensure anatomic reduction
2. To minimize potential long-term morbidity from associated soft tissue and articular cartilage injuries
3. To more accurately prognosticate long-term ankle function

Arthroscopic Portals (Figs. 40.1, 40.2, and 40.3), (Gumann and Hamilton 2011)

Anterior portals
Anterolateral
Anteromedial

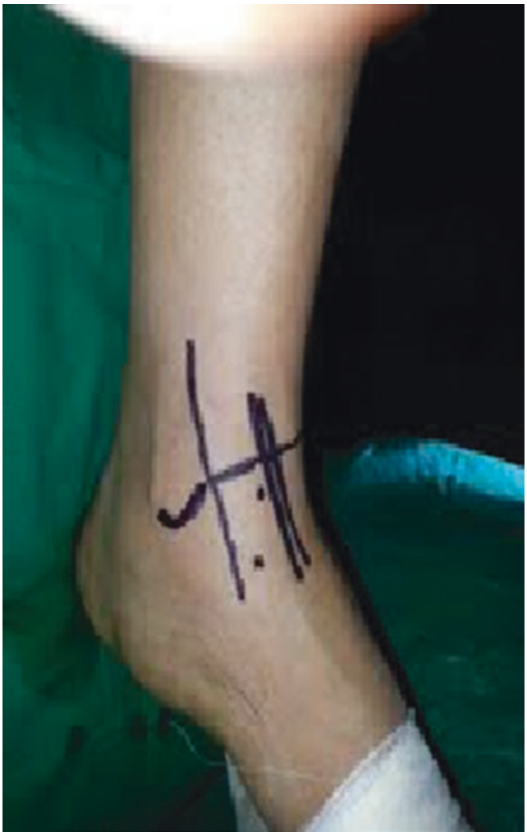

Fig. 40.1 Superior and inferior anteromedial portals

Fig. 40.2 Superior and inferior anterolateral portals

Fig. 40.3 Posterolateral portal

Anterocentral (rarely used)
Posterior portals
Posterolateral
Posteromedial (rarely used)
Transmalleolar portals
Transtendinous
Subtalar portals

40.1.1 Anterior Portals (Most Commonly Used Portal)

The anterolateral portal is located at the level of tibiotalar joint just lateral to the peroneus tertius tendon. Injury to the dorsal cutaneous nerve can be avoided by plantar flexing the ankle and inverting the foot to stretch the nerve, allowing it to be identified by palpation. The anteromedial portal is located at the ankle joint line medial to the anterior tibial tendon. Injury to the saphenous vein and nerve can be avoided by staying close to the tendon and not straying too far medially.

40.1.2 Posterior Portals

A posterolateral portal located just lateral to the Achilles tendon at the level of joint line is commonly used. Care must to avoid injuring the small saphenous nerve or vein**.**

40.1.3 Preoperative Planning

Surgical evaluation: Preoperative radiographs include anteroposterior, lateral, and mortise views. Often, CT scanning is required to identify complex fracture patterns, intra-articular injuries and epiphyseal injuries. MRI is essential to diagnose the extent of ligamentous injury, bone oedema, articular cartilage damage and capsular soft tissue affection.

Timing of surgery: Arthroscopic evaluation and fracture treatment are performed as soon as possible after injury, preferably within 6 h, before the oedema sets in. After only a few hours post-injury, oedema significantly increases. If significant oedema is present, it is advisable to wait for 7–14 days, until the swelling resolves.

The skin wrinkle test is indication of oedema resolution. Once oedema resolves, an effective fracture management treatment plan can be made for the use of arthroscope-assisted fixation.

40.1.4 Arthroscopic Examination of the Ankle Joint

Arthroscopic examination of the ankle is usually performed under spinal or general anaesthesia. The patient is generally placed in a supine position (Fig. 40.4). The knee is flexed with a tourniquet applied to the thigh. A 30° 4 mm scope is recommended. With the availability of a smaller 2.7 mm arthroscope, the need for wide angle optics is limited. A smaller arthroscope is ideal for ankle arthroscopy, as it allows for ease of passage into the posterior compartments and provides effective direct vision.

A fluid pump, with low-level pressure controls, can be used to enhance vision clarity. Generally with most injury patterns, the joint can be entered without any distraction, as an unstable mortise allows for easier instrument passage. Soft tissues should be carefully observed for swelling due to forced inflow or inadequate outflow. Distraction is occasionally needed to help gain access to the ankle joint. To avoid operating area congestion, the image intensifier should be placed opposite the surgeon.

40.1.5 Technique

Sterile preparation of the lower half of the leg, ankle and midfoot is preferred. Manual or noninvasive distraction is used when necessary. Portal placement locations should be marked in advance taking into account intra-articular fracture characteristics. Proper anteromedial portal location can be verified by inserting a #18 spinal needle and directing it towards the joint centre. The joint can then be flushed with 20 mL of saline solution to washout the hematoma. The lateral portal can be created by introducing a #20 spinal needle at the desired location, taking care to avoid injury to the neurovascular and tendinous structures. To minimize the risk of neurovascular injury, all portal incisions should only be through the skin layer. Thereafter, the portal creation should be performed using a blunt trocar to penetrate the joint capsule. We recommend use of a #11 scalpel blade to make a 5 mm long vertical incision at the joint line. A mosquito clamp is then used to widen the portal. After blunt trocar use to penetrate the joint capsule, a cannula can be passed towards the joint centre. Care should be taken to a avoid scuffing the articular surface. With inflow maintained through the arthroscope in the anterolateral portal, the anteromedial portal can be created using a #20 spinal needle under direct vision. In case of extensive traumatic synovitis, synovectomy may be necessary. Arthroscopic ankle joint examination

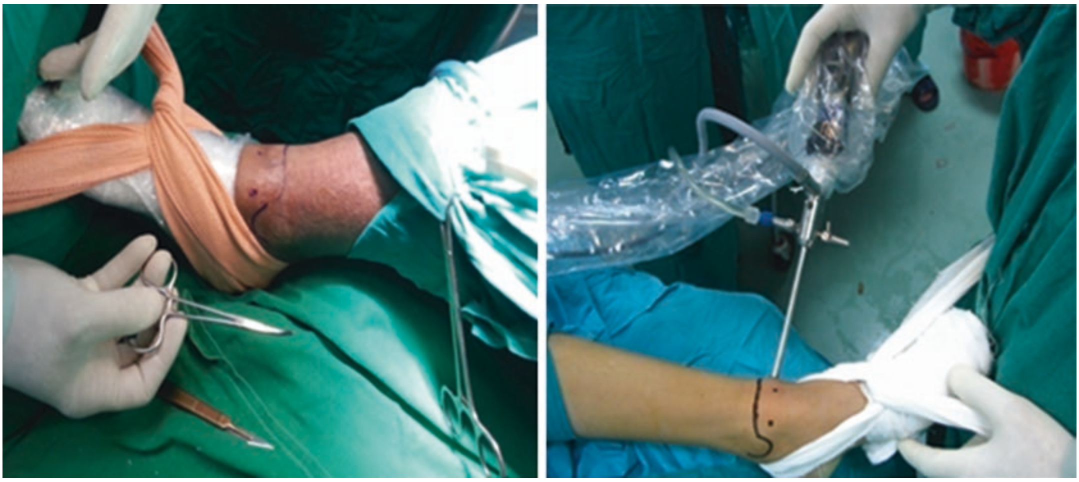

Fig. 40.4 Supine position with traction applied using a gauze bandage attached to the surgeon's waist

should be performed through the anteromedial portal first and then through the anterolateral portal. Posterolateral and posteromedial portals may be necessary to thoroughly assess the ankle joint for loose bodies and articular cartilage injuries. To avoid the potential for creating an open fracture with invasive distraction, manual or noninvasive distraction may be used.

40.1.6 Arthroscopic-Assisted Reduction of the Fracture and Fixation (Bonasia et al. 2011; Gumann and Hamilton 2011; Turhan et al. 2013)

40.1.6.1 Medial Malleolar Fracture

Adequate lavage helps remove bone debris, blood clots and loose chondral pieces from the joint fracture area. The fracture site is thoroughly evaluated, gently debrided from anteromedial or anterolateral portals. A dental or microfracture pick or nerve root retractor can be used to disimpact any depressed fracture fragments.

Reduction of the medial malleolar fracture is achieved through a combination of extraarticular manual and intra-articular manipulation using single or double Kirschner wires as “joysticks”, under fluoroscopic control. At times, the periosteum may be entrapped, and a small plafond tibial fragment may hinder reduction, in which case mini-open reduction is advisable to remove the periosteum and disimpact the depressed fragment to achieve anatomical reduction and fixation. Once the reduction is completed, it is important to drill the guide wire up to the fracture line and then reduction is further achieved and maintained by using the guide wire “joystick” technique. Further drilling is performed through the fracture line to the appropriate bone segment. After accurate anatomic fixation is obtained, definitive fixation can be performed using 4 mm cannulated cancellous screws of appropriate length by threading them over the guide wire under image control guidance. One screw is generally sufficient, provided the fragment is small. However, when there is a large fragment, two screws may be needed.

40.1.6.2 Lateral Malleolar Fixation

In the case of lateral malleolar fracture, the arthroscope is normally maintained in the anteromedial portal, and the anterolateral portal is used as the working portal. After thorough washing and debriding of lateral gutter synovitis, the intra-articular fracture line can be easily visualized. Proper fibular fracture reduction and lateral malleolus articular facet rotation restoration are extremely important, to restore appropriate fibula length. This can be done manually under traction, and the lateral malleolus may be held in with a towel clip to maintain the reduction. In minimally displaced fibula or lateral malleolus fracture cases, fixation is achieved by using a nail introduced percutaneously under image intensifier guidance through the lateral malleolus tip. As the reduced fracture is being maintained by manual pressure and traction, an entry point is made to introduce a bone awl at the midpoint of the lateral malleolus. The awl is then passed distal to proximal and advanced under fluoroscopic guidance to a location just above the fracture site. This helps to determine the approximate size of the medullary cavity. The awl is then replaced by an appropriately sized nail. The nail is then advanced into the medullary cavity under image guidance. A cannulated screw can also be used while maintaining fracture reduction and stabilization.

In comminuted lateral malleolus, segmental or more displaced fibula fracture cases, lateral malleolus reduction can be very difficult, as it is important to maintain both lateral malleolus rotational alignment and fibular length. To effectively maintain fibula fracture reduction, an external reduction clamp or Kirschner wire passed at right angles to the fracture site may have to be used. An inferior-to-superior mini-incision at the inferior lateral malleolus and extraperiosteal soft tissue enables tunnel creation. An appropriately sized and one third tubular plate contoured to the shape of the fibula is inserted through the tunnel under fluoroscopic image guidance. The fibula is first percutaneously fixed at the distal malleolar level and then proximally, under fluoroscopic image guidance. The plate may also be passed through a tunnel from superior to inferior direction and then fixed percutaneously. In cases

Fig. 40.5 Figures show postop radiographs with cannulated screws in the medial malleolus and a nail in the fibula

where the fracture line is more proximal to the syndesmosis, for instance, a comminuted fracture of the lateral malleolus, open reduction and internal fixation may be needed.

40.1.6.3 Bimalleolar Fractures

In the case of a bimalleolar fracture, the fibula fracture should be reduced and fixed first to maintain fibular length. The principle of first reducing and fixing the lateral malleolus to stabilize the lateral wall is vital and necessary before attempting medial malleolus reduction. The lateral malleolus is secured using a cannulated cancellous screw or a nail of appropriate size (Fig. 40.5).

A non-displaced bimalleolar or trimalleolar fracture can be readily identified arthroscopically and reduced percutaneously using slight manual pressure without much difficulty. The reduction can be achieved through intra-articular use of a dental or microfracture pick or reduction forceps or externally using towel clips. Once the reduction is verified, percutaneous fracture fixation is performed from distal to proximal using fluoroscopic guidance. One or two appropriately size cannulated cancellous screws are inserted to stabilize the fracture. For a vertical medial malleolar fracture, guide wire drilling should be at right angles to the fracture. An additional anti-glide percutaneous plate may be used if the metaphyseal extension is more than 2 cm. A transverse medial malleolus fracture is often difficult to reduce due to periosteal entrapment. It is important to remove the entrapped periosteum and align the fracture fragment under arthroscopic view before attempting to achieve reduction using a Kirschner wire as a “joystick”. In the case of trimalleolar fracture, the posterior malleolus fracture is displaced and is more than 20% of the articular surface. For this fracture type, it is important to stabilize the fragment with guide wire introduced at right angle to the fracture line from anterior to posterior or posterior to anterior (trans-Achilles tendon) under fluoroscopic guidance and then fix the fracture with an appropriately sized cannulated screw.

40.1.7 Maisonneuve Fracture (Imade et al. 2004; Jones et al. 2003; McGillion et al. 2007; Sri-Ram and Robinson 2005; Salvi et al. 2009)/Syndesmotic Injuries

In this fracture type, the proximal fibular fracture is often non-displaced or minimally displaced, and there is diastasis at the fibular syndesmosis due to syndesmotic ligament disruption. There is some t of indirect fixation of the proximal fibular fracture through the envelope of the muscle mass around the fibula. The ankle is arthroscopically evaluated, and the syndesmosis debrided. The syndesmotic injury needs to be stabilized with a large pointed reduction forceps from fibula to tibia. Two trans-syndesmotic screws should be used percutaneously for fixation under fluoroscopic guidance. In chronic syndesmotic injury, the interposed scar tissue on the lateral side is debrided. The medial clear space is also cleared, and the fibula is mobilized into the incisura. Thus, the technique involves debridement of all interposed scar tissue at the syndesmosis, as well as the medial clear space, prior to attempting mobilization of the fibula into the incisura. When debriding the syndesmosis in particular, the arthroscope is placed in the anteromedial portal, and the shaver is placed in the anterolateral portal to enable direct tibiofibular syndesmotic access. Preparation of the deltoid ligament medial space/gutter is performed with the arthroscope located in the anterolateral portal and the shaver in the anteromedial portal. Preparation of the syndesmosis involves resection of enough tissue to allow direct apposition of the fibula to the tibial incisura. After satisfactory preparation of the syndesmotic space, the syndesmosis is reduced by placing two external reduction clamps on the tibia and fibula to align and appose the two bones, one at the superior level and the other at the inferior aspect of the syndesmosis. The clamps should be oriented in the same direction of the tibiofibular axis to avoid anterior or posterior migration. The aligned surfaces should be verified arthroscopically, under fluoroscopic guidance for proper rotational alignment and lateral malleolar facet reduction. Once this is achieved, two guide wires are passed from lateral to medial through the fibula to the tibia. The superior guide wire should be positioned just below the upper level of the syndesmosis. The inferior guide wire should be positioned at the lower level of the syndesmosis. Following this, 4 mm cannulated screws of appropriate size are threaded over the guide wires (Fig. 40.6). Care should be taken not to penetrate the medial tibial cortex.

40.1.8 Juvenile Intra-articular Epiphyseal Fractures (Imade et al. 2004; Jennings et al. 2007; Jones et al. 2003; McGillion et al. 2007)

The most common fractures encountered in the juvenile population are the Tillaux and triplane fractures of the distal tibia. The injury mechanism involves a traumatic external rotation of the foot on the tibia and the lateral distal tibial epiphysis.

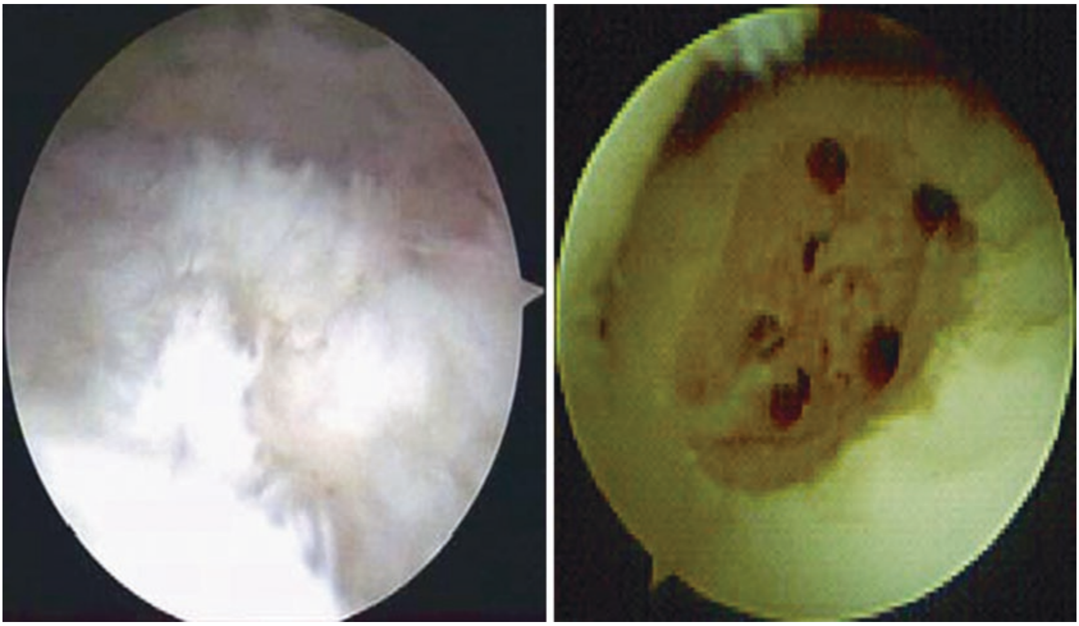

Fig. 40.6 Pre- and post-operative images

This results in a fracture which extends through all three planes (axial, sagittal and coronal) disrupting the tibial plafond. The fracture patterns are normally combinations of Salter-Harris types II, III and IV. Plain radiographs may not provide complete information, to assess the extent of epiphyseal damage. A CT scan with 3D reconstruction can provide vital information on the size, displacement and degree of articular congruency. This is vital to treatment planning. This will also help verify fragment alignment and proper screw placement. Intra-articular displacement greater than 2 mm is a generally accepted indication for reduction and fixation. After inserting the arthroscope, thorough joint debridement should be performed. To facilitate fracture site opening, external rotation has to be maintained during the procedure. After clearing the joint of debris, a large bone clamp is placed in the region immediately above the anterolateral portal on the distal tibial epiphyses, just medial to the edge of the fibula. The other jaw of the reduction clamp is placed on the crest of the posteromedial tibia, in the region of the metaphyses just above the epiphyses. The clamp is tightened, under arthroscopic and fluoroscopic guidance, to assure proper anatomical reduction. Under fluoroscopic guidance, a guide wire is drilled laterally from the medial side of the epiphyseal portion of the tibia parallel to the epiphyses. Care must to be taken to protect the epiphyses from damage by not crossing the epiphyseal plate. A fully threaded or partially threaded cannulated screw of appropriate size is inserted over the guide wire traversing the fracture line as perpendicular as possible. Arthroscopic verification of adequate interfragmentary compression and anatomical reduction under fluoroscopic guidance is performed as the screws are tightened.

40.2 Figures 40.7 and 40.8: Talar Lesions (Gholam et al. 2000; Subairy et al. 2004; Thordarson et al. 2001a)

Osteochondral lesions of the talus are common. They are commonly seen in the anterolateral, anteromedial and posterolateral regions (Fig. 40.7). The lateral lesion has been described as shallow and wafer-shaped and located at the more anterior portion of the talus. Small, anterolateral chondral lesions, less than 8 mm, are normally debrided and loose fragments removed through the anterolateral portal. After removal of the loose fragment, the exposed bed of the talus should be treated with microfracture (Fig. 40.8). If the fragment is larger than 8 mm, it necessitates fixation. The inflow should be from the posterolateral portal and instruments should be inserted through the anterolateral portal. A cannula can be used to manipulate the fragment for reduction. A Kirschner wire is used for temporary fixation and then replaced by absorbable pins for definitive treatment. A similar strategy may be used to treat medial lesions, which often are deeper, cup-shaped and located at the posterolateral aspect of the talar dome.

Posterolateral talar lesions are best visualized through the posterolateral portal, and instruments are passed from the anterolateral portal. Inflow is from the anteromedial portal. Type 1 fractures benefit from stable arthroscopic fixation. Open surgical technique generally needs to be per-

Fig. 40.7 Osteochondral lesion of talus

Fig. 40.8 After microfracture

formed for fractures not accessible using the arthroscope. Type 3 fractures respond well to conservative treatment. However, type 2 and 4 fractures appear to be best treated by an early removal of the fracture fragments rather than delayed surgery. Minimally displaced talar dome fractures are reduced manually, held with reduction clamps and then fixed with guide wires passed either from posterior to anterior from the posterior process to the head or from anterior to posterior from the head to the posterior process. This is done under fluoroscopic guidance with arthroscopic visualization and verification of chondral surface reduction. One or two cannulated screws (or Herbert screws) of appropriate size are then threaded over the guide wire for final reduction and fixation.

40.3 Tibial Plafond Fractures

Arthroscopic-assisted surgery has a role in Allgöwer 1 and 2 type fractures. Severely comminuted or Ruedi-Allgöwer 3 type fractures are beyond the scope of arthroscopic treatment. Extravasation of fluid poses a significant risk for development of compartment syndrome, and soft tissue must be monitored meticulously to minimize this risk. An external fixator may be placed preoperatively to provide adequate traction across the joint and to serve as postoperative immobilization.

After successful portal placement, the ankle is thoroughly lavaged and debrided of any loose fragments. Closed reduction, intra-articular manipulation with an elevator is performed and maintained with guide wires. After reduction, final internal fixation is completed with cancellous cannulated screws under arthroscopic visualization and fluoroscopic control.

40.3.1 Postoperative Management

The ankle should be protected in a below knee posterior plaster slab, for 2 weeks. Then intermittent ankle range of motion within pain-free limits is allowed. The patient maintains non-weight-bearing ambulation status for 4–6 weeks depending upon fracture type and healing status. They are then progressed to partial weight bearing through the 10th postoperative week. Full weight bearing is not allowed until fracture union is verified radiographically. Ankle mobilization and strengthening exercises and proprioceptive exercises are continued until full function has been restored (Fig. 40.9).

40.4 Discussion

Ankle fractures are associated with a high incidence of concomitant soft tissue and osteochondral pathology. Very often these injuries go unrecognized and unattended giving rise to inferior clinical outcomes (Boraiah et al. 2009). Ono et al. reported a greater incidence of osteochondral injury identified by arthroscopy in patients that displayed poor functional outcomes at a mean of 12.4 months after open treatment of ankle fractures (Ono et al. 2004). Assessment of concomitant intra-articular pathology in the setting of ankle fracture provides important prognostic information. Larger lesions (osteochondral) require more definite treatment such as osteo-

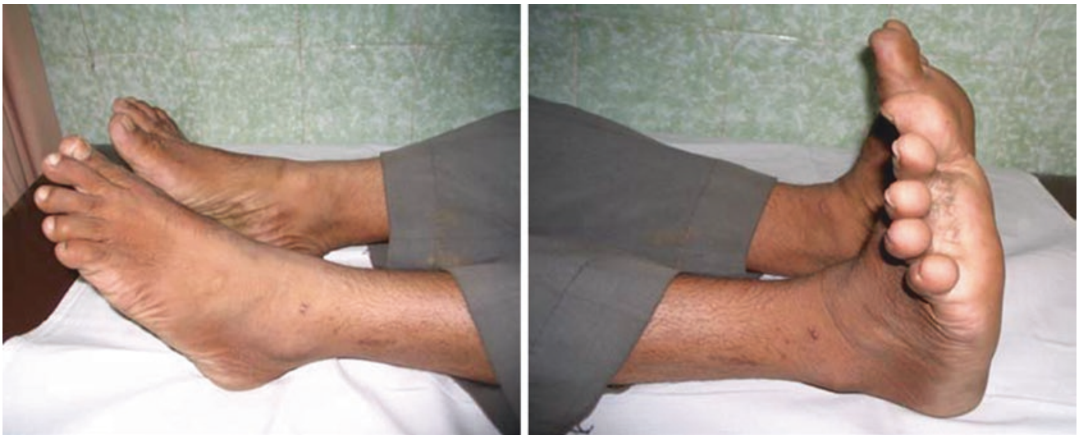

Fig. 40.9 Post-surgical ankle plantar and dorsiflexion

chondral autograft transfer (OATS). Unless more elaborate procedures are used, inferior outcomes are likely. There are not many studies that define the exact role of arthroscopy for therapeutic purposes in the setting of acute ankle fractures. Some studies have reported outcomes of arthroscopic treatment of intra-articular sequelae after operative ankle fracture management. According to Takao et al., ankle arthroscopy is indispensable for accurate diagnosis of a tibiofibular syndesmosis injury (Takao et al. 2003). Sri-Ram and Robinson (2005) suggested that arthroscopy should be considered as part of syndesmotic injury management when conventional imaging techniques fail to identify syndesmotic disruption. Vallier et al. (2004) and Ono et al. (2004) suggested that further studies are needed to evaluate the efficacy of arthroscopy for treating ankle injuries. Use of MRI can also help guide treatment plans to better manage osteochondral defects in relation to an ankle fracture.

40.5 Conclusion

Use of arthroscopy in ankle fractures is promising, as it facilitates excellent viewing of the fracture pathology with its intra-articular findings, which are often missed in open reduction with internal fixation. It allows the surgeon to reduce the fracture to anatomic congruency under direct vision and fluoroscopic guidance. Arthroscopic techniques for intra-articular fracture fixation offer the advantage of superior visualization and reduction of the articular surface, diagnosis and treatment of associated soft tissue injuries and reduced invasiveness. It is less invasive, more cosmetic and less painful and allows the patient to leave the hospital early and return to work faster. (Sherman et al. 2015; Wood et al. 2014).

40.5.1 Tips and Pearls for Effective Arthroscopy for Ankle Fracture (Hepple and Guha 2013; Thordarson et al. 2001b)

1. It is of utmost importance that ankle fracture arthroscopy should be performed first when the skin shows wrinkling after swelling subsides.
2. To ensure proper viewing, the ipsilateral hip should be lifted up by a sand bag to control external rotation.
3. The surgeon should carefully mark the position of important neurovascular and tendinous structures, including the superficial peroneal nerve, to which the anterolateral portal should be lateral, and the tibialis anterior tendon, to which the anteromedial portal should be medial.
4. To prevent iatrogenic intra-articular damage, traction and counter traction should be used when necessary to make joint access easier.

5. The joint should be distended with 10–20 mL saline solution to ensure appropriate portal location before introducing the surgical instruments.
6. Blunt dissection with a mosquito clamp is necessary to avoid neurovascular injury.
7. To create a clear visual field, the ankle should be evacuated of any hemarthrosis.
8. It is advisable to use gravity inflow or low-pressure inflow to prevent excessive soft tissue fluid extravasation.
9. The procedure should be performed expeditiously to minimize fluid extravasation.
10. The surgeon should be experienced in conventional ankle fracture management before introducing arthroscopic techniques.
11. Detailed fracture assessment and documentation is essential for surgical management and more effectively prepare for any future interventions.
12. A small arthroscope 2.7 mm is needed in most cases.
13. A wide variety of small diameter arthroscopic instruments should be available to facilitate fracture site access and surgical procedure.
14. The role of external fixators and ankle joint distractors for ankle arthroscopy cannot be underestimated.

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Minimally Invasive Management of Osteochondral Defects to the Talus

Jari Dahmen, Kaj T. A. Lambers, Mikel L. Reilingh, and Gino M. M. J. Kerkhoffs

41.1 Introduction

An osteochondral defect (OCD) to the talus or, alternatively, osteochondral fracture of the talus represents a pathologic lesion of the articular cartilage and its subchondral bone. These lesions can occur in up to 70% of acute ankle fractures and sprains (Alexander and Lichtman 1980; Draper and Fallat 2000; Hintermann et al. 2000; Saxena and Eakin 2007). The quality of life of patients suffering from an OCD of the talar dome can be severely deteriorated, and an extensive diversity of interventions exists to treat these defects. Controversy remains amongst orthopaedic surgeons with reference to identifying *the* golden standard for primary defects and those defects that had failed prior surgical intervention(s). In order to aspire to identify optimal treatment protocols, multiple review articles and current concept studies have been published (van Bergen et al. 2008; Giannini and Vannini 2004; Hannon et al. 2014; McGahan and Pinney 2010; Murawski and Kennedy 2013; O'Loughlin et al. 2010; Savage-Elliott et al. 2014; Vannini et al. 2014; Wodicka et al. 2016; Zengerink et al. 2006). Moreover, a number of systematic reviews have been conducted over the course of the past 10 years (Donnenwerth and Roukis 2012; Loveday et al. 2010; Zengerink et al. 2010). More recently, the first systematic review investigating solely primary talar OCDs by Dahmen et al. (2018) concluded that due to the heterogeneity of the literature and the low level of methodological evidence of the included studies, none of the surgical procedures were identified to be superior to others. This indicates that since the systematic review of Zengerink et al. (2010) which included articles up to 2006, we still have not advanced significantly further 10 years later, illustrating that establishing a definite recognition of the clinically most effective treatment strategy for talar OCDs remains open to debate. Although it is clear that substantial debate persists with reference to the treatment of talar OCDs, one aspect orthopaedic surgeons do acknowledge is that the treatment of talar OCDs requires a minimally invasive management protocol. In this chapter, we will therefore present a historical perspective on talar OCDs, provide a critical insight into current conservative management and minimally invasive surgical treatment for primary defects

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and those that had failed prior surgical intervention(s) and describe a promising arthroscopic internal fixation technique, known as the Lift, Drill, Fill and Fix (LDFF) technique.

41.2 Historical Perspective

The current rationale for treating talar OCDs commenced when Hunter (1743) stated that “From Hippocrates down to the present age, ulcerated cartilage is a troublesome disease; when destroyed, it is not recovered”. In 1558 Ambroise Pare identified loose bodies in the knee joint, and it was almost 200 years later when Monro (1856) reported the presence of cartilaginous bodies in the talocrural joint. Paget (1870) further described the lesions investigating patients with knee pain, but Franz König (1887) was the first to coin the term *osteochondritis dissecans*, as he suggested that corpora libera originating from the articular surfaces of varying joints, amongst them the elbow and knee joint, were a consequence of necrosis accompanied by dissecting inflammation. Kappis (1922) noticed great similarity between lesions of the talocrural joint and the ones recognized in the knee, which led to the first referral of osteochondritis dissecans of the ankle. Ten years later, a talar intra-articular fracture was reported by Rendu (1932) having found resemblances to the osteochondritis dissecans as described by Kappis. Partially due to a publication by Rödén et al. (1953) which concluded that the great majority of the lesions presenting laterally on the talus were secondary to trauma, the definition of osteochondritis appeared to be a misnomer as inflammation was not considered to be the main contributing determinant for the development of a talar OCD. The scientific contribution of Berndt and Harty (1959) was of clinical significance in concluding that in addition to the lateral defects, medial osteochondral lesions were also caused by trauma. It has been accepted that a traumatic event appeared to be *the* major etiological factor. Berndt and Harty (1959) designated the lesion as a transchondral fracture to the talus. Frequently utilized descriptive diagnoses include talar dome fracture, flake fracture and osteochondral lesions, defects and fractures. Their classic article formed the clinical basis of our contemporary indications for surgery, and since 1959 an extensive range of treatment modalities have been developed and subsequently practiced thereafter.

41.3 Non-surgical Management

Non-surgical treatment of a symptomatic OCD can consist of a combination of the following options: cast immobilization, physiotherapy, restriction of sporting or working activities and administration of non-steroidal anti-inflammatory drugs (NSAIDs). The objective is to unload the damaged articular cartilage, thereby aiming at prevention of necrosis and reduction of joint oedema. Partially detached fragments might have the possibility to heal to the underlying bone when undergoing non-surgical management. It has been reported that skeletally immature patients show greater intrinsic healing capacity of immature articular cartilage. However, human and animal investigations are contradictory (Bauer et al. 1987; DePalma et al. 1966; Kim et al. 1991; McCullough and Venugopal 1979; Vasara et al. 2006; Wei et al. 1997; Wei and Messner 1999). A study by Reilingh et al. (2014) including only skeletally immature children with a chronic talar OCD concluded that eventually 92% of initially non-surgically treated children were dissatisfied with the treatment results and consequently were scheduled to undergo surgery. Despite success percentages of non-surgical treatment alone being reported to be substantially below 50%, it should in all cases be considered as the initial treatment option (Dahmen et al. 2018; Zengerink et al. 2010). More recently, Klammer et al. (2015) identified that 86% of the non-surgically treated minimally symptomatic talar OCDs were pain-free or less painful at the final follow-up at 2 years, and radiological assessment (MRI) revealed that 88% of the patients remained unchanged or even showed remission in terms of staging or lesion size. This might indicate that minimally symptomatic lesions corresponding to the lower Berndt and Harty (1959) grades, such as the grade I and II lesions, could potentially benefit to a greater clinical extent from non-surgical management than previously suspected.

41.4 Surgical Management

41.4.1 Arthroscopic Bone Marrow Stimulation (BMS)

O'Driscoll (1998) postulated that treatment options for damaged or lost articular cartilage can be grouped into four principles. It can be restored, replaced, relieved or resected. First-line, that is, primary surgical treatment for talar OCDs generally incorporates restoration of the articular cartilage and repose on the intrinsic capacity of the articular cartilage and the subchondral bone to heal itself. In line with this clinical train of thought is the management of talar OCDs by arthroscopic bone marrow stimulation (BMS). Preoperatively, a computed tomography (CT) scan can be taken (Fig. 41.1a). During arthroscopy the surgeon executes curettage of all the unstable cartilage as well as the present necrotic subchondral bone—in the case of the presence of subchondral cysts, these are opened and curetted—after which the subchondral bone is perforated by means of drilling or microfracturing. This allows intraosseous blood vessels to disrupt so that multipotent mesenchymal cells can migrate into the defect thereby inducing the formation of a fibrin clot, which will subsequently transform into fibrocartilage—articular cartilage/collagen type (O'Driscoll 1998). At follow-up, a postoperative CT scan can be taken (Fig. 41.1b). The most important advantages of BMS procedures are the relative ease and minimal invasiveness of the technique, the quick recovery and thus the fast return to sports or work. Therefore, this particular technique is currently regarded as the golden standard for primary talar osteochondral defects. There are, however, a number of concerns when critically analysing BMS. Firstly, a number of systematic reviews on the outcomes of BMS have been conducted, and the success rates for primary talar OCDs are reported around 79–80%, according to Dahmen et al. (2018) and Donnenwerth and Roukis (2012). This shows that yet there is substantial room for improvement, which could be related to a number of other elements to be considered associated with the arthroscopic BMS technique. Firstly, microfracturing does not aim at the preservation of a hyaline cartilage layer, but rather promotes the formation of fibrocartilage which decreases in quality over time, resulting in osteoarthritic

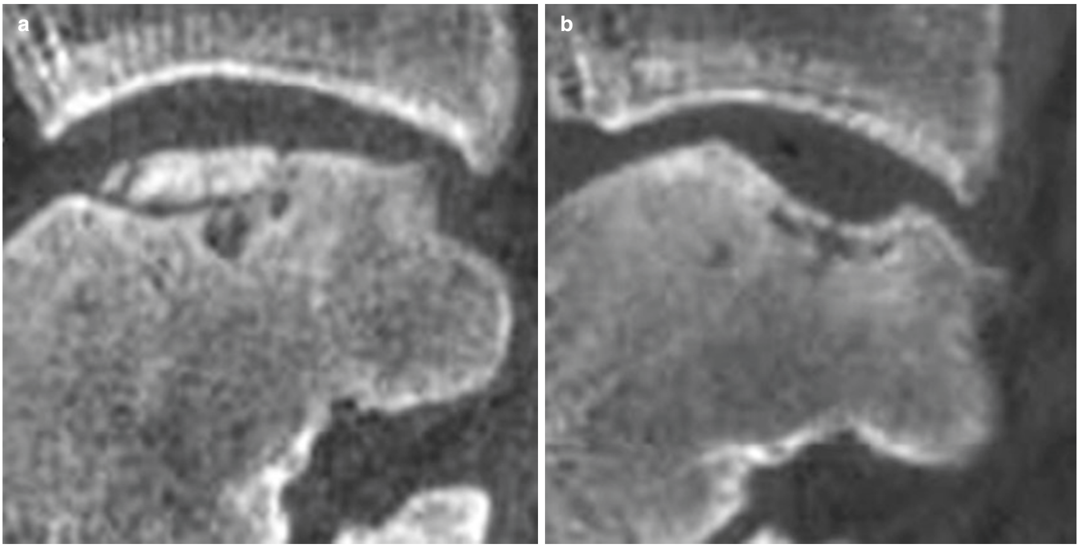

Fig. 41.1 Sagittal CT scans of a talar osteochondral defect of the medial dome (right ankle). **(a)** Preoperative CT scan. **(b)** One-year postoperative CT scan after arthroscopic debridement and bone marrow stimulation (same ankle)

changes (Lynn et al. 2004). This is supported by evidence from several studies (Ferkel et al. 2008; Lee et al. 2009; van Bergen et al. 2013). Progression of ankle osteoarthritis was observed in 33–34% of the patients after arthroscopic debridement and bone marrow stimulation of the talar osteochondral defects at mean follow-up terms of 71 and 141 months, in the studies of van Bergen et al. (2013) and Ferkel et al. (2008), respectively. Moreover, Reilingh et al. (2016) found that the subchondral bone plate was depressed in 74% of the cases at 1-year follow-up on computed tomography analysis, and second-look arthroscopy revealed that 12 months postoperatively, 40% of the defects had incompletely healed with fibrocartilage (Lee et al. 2009). Additionally, since type I articular cartilage demonstrates inferior wear characteristics, deterioration of the natural ankle joint congruency is associated with repaired articular surface degradation. This poses the subsequent question as to what extent natural ankle joint congruency can be mirrored after using a BMS procedure (Marsh et al. 2002; Qiu et al. 2003; Stufkens et al. 2010). Another question arising is to what extent it is feasible to perform BMS for defects with sizes larger than 1.5 cm in diameter—alternatively 150 mm^2 or 1.5 cm^3. This question has interested clinical researchers, and initially it was postulated that the cut-off point for performing a BMS procedure was 15 mm (in diameter), as studies by Choi et al. (2009) and Chuckpaiwong et al. (2008) indicated that beyond this size, inferior clinical outcomes were observed. Moreover, in a more recent study, a systematic review by Ramponi et al. (2016) shows that the cut-off point might be even lower, around the size of 107.4 mm^2 in area or 10.2 mm in diameter which offers novel insight into the critical defect size for performing BMS procedures in order to assure successful clinical outcome.

41.5 Retrograde Drilling

Another form of minimally invasive surgery to treat osteochondral defects of the talus is performing a retrograde drilling procedure. Similarly to the BMS procedures, it aims to stimulate the intrinsic restoration of the articular cartilage, and it is executed under radiographic control, thereby avoiding injury to the articular cartilage as it is performed in a retrograde, transtalar manner. No articular cartilage is removed, and via a posterolateral approach or through the sinus tarsi, the talar OCD can be reached after which a Kirschner wire is advanced toward the lesion and subchondral drilling will occur. A major indication for a retrograde drilling procedure is the presence of intact intra-articular talar hyaline cartilage and/or the presence of a large subchondral cyst. Another indication for performing this non-transarticular procedure is when the osteochondral defect cannot be reached via the common anteromedial and anterolateral arthroscopic portals (van Dijk and van Bergen 2008). Additional insertion of cancellous bone grafts into the defect may be a valid option, should subchondral cysts of extensive nature be existent. In a case control study by Kono et al. (2006), retrograde drilling in 30 patients showed promising results in terms of arthroscopic assessment 1 year postoperatively due to the fact that the retrograde drilling group achieved greater improvement in the articular cartilage condition in comparison with 19 patients that were treated with a transmalleolar (antegrade) drilling approach.

41.6 Osteochondral Fragment Fixation

41.6.1 Surgical Technique: Arthrotomy

In order to tackle the limitations of the BMS technique, such as osteoarthritic advancement, an irregular subchondral bone plate, the transformation of a fibrin clot into fibrocartilage instead of hyaline cartilage and a cut-off point for maximum lesion size, internal fixation of the osteochondral defect fragment has been described as an alternative surgical technique for treating talar OCDs. The ideal indication for internal fixation is a primary, large (anterior-posterior or medial-lateral diameter > 10 mm on computed tomography) symptomatic osteochondral defect of the talus in patients with persistent complaints for more than 1 year without presence of osteoarthritis (van Dijk et al. 1997). For both the open and arthroscopic technique, a preoperative sagittal CT scan is taken (Fig. 41.2a). We have developed an open surgical fixation technique, in which a medial or lateral arthrotomy is utilized with optional malleolar osteotomy in order to allow for an appropriate visibility of the osteochondral defect and to create optimal working access. Thereafter, the talar OCD is exposed, in order to create an osteochondral flap with the use of a knife. It is essential that the posterior side of the osteochondral flap is in all times left intact, as this acts as a lever. By means of a chisel, the flap will be lifted (like the hood of a car), and after this the attached bone of the fragment is debrided, and the osteosclerotic area of the bed and the bone flake of the osteochondral fragment are drilled in order to induce revascularization. In case of the presence of (a) subchondral cyst(s), its contents must be curetted and the circumference of its sclerotic wall drilled. In order to fill the debrided and drilled fragment, one harvests cancellous bone from the distal tibial metaphysis or, alternatively, from the medial malleolus. Prior to fixating the fragment, one must pay close attention to correctly aligning the osteochondral fragment. The fixation of the fragment procedure can be executed by means of a permanent screw or an absorbable screw. The screws should be positioned under the articular surface.

41.7 Surgical Technique: Arthroscopic Lift, Drill, Fill and Fix (LDFF) Procedure

Evidently, the open internal fixation technique as described above does not, to a great extent, follow the principles of minimally invasive surgery. We therefore developed an arthroscopic procedure in order to achieve a lower complication rate and a faster rehabilitation course (Zengerink and van Dijk 2012). The arthroscopic procedure consists of the following steps which will be elaborated further below: Lift, Drill, Fill and Fix (LDFF) (Kerkhoffs et al. 2016). The operation is carried out as an outpatient procedure either under general or spinal anaesthesia, and the patients are placed in a supine position with slight elevation of the ipsilateral buttock. A support is placed at the contralateral side of the pelvis of the patient. The heel of the affected foot rests on the very end of the operating table so that the orthopaedic

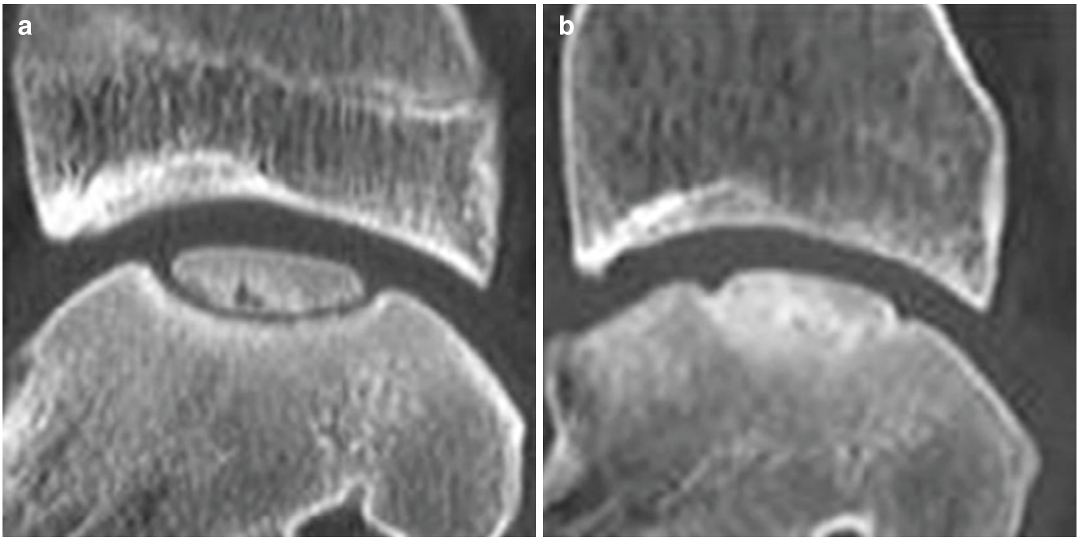

Fig. 41.2 Sagittal CT scans of a talar osteochondral defect of the medial dome (right ankle). (**a**) Preoperative CT scan. (**b**) One-year postoperative CT scan after arthroscopic Lift, Drill, Fill and Fix (LDFF) (same ankle)

surgeon has the ability to dorsiflex the ankle to the full extent by leaning against the foot sole, and because of this particular position, the table can be utilized as a lever when maximal plantar flexion is necessary. When required, the surgeon will use a non-invasive soft-tissue distraction device. The talocrural joint is visualized by means of the common anteromedial and anterolateral arthroscopic portals. Subsequent to this, the distal tibial rim is removed in order to facilitate optimal ankle joint access, and with a probe, the exact location of the talar OCD is identified. In order to prepare for the first step of the LDFF technique, a beaver knife is used to create a sharp osteochondral flap (Fig. 41.3a, b)**.** Just as for the open arthrotomy procedure described above, the posterior side of the flap should be left intact and can then be used as a lever, allowing for an anterior lift with use of a chisel (*lift*) (Fig. 41.3c). The second step of the procedure which aims at the promotion of revascularization, *drill*, consists of debriding and drilling the attached bone of the osteochondral flap and the osteosclerotic area of the bed (Fig. 41.3d). It must be stated that, as with the open procedure, it is important that any subchondral cysts present should also be debrided and punctured. In the third step (*fill*), the debrided and drilled defect is filled with cancellous bone harvested from the distal tibial metaphysis by a chisel. Bony flakes are then transported into the defect using a grasper (Fig. 41.3e, f). The ultimate step (*fix*) is fixating the fragment, and this is only performed after having achieved a correctly aligned osteochondral flap. For fixation, Bio-Compression Screw(s) (Arthrex Inc., Naples, USA) or multiple chondral darts (Arthrex Inc., Naples, USA) are utilized (Fig. 41.3g, h). Darts and screws can also be combined in order to create a sufficient fixation method.

41.8 Osteochondral Fragment Fixation: Postoperative Management

Subsequent to finishing the arthroscopic LDFF technique as well as the open fixation procedure, a short-leg, non-weight-bearing cast is applied for a period of 4 weeks postoperatively. After this 4-week period of immobilization, the foot is placed in a short-leg walking cast in a neutral flexion and neutral hindfoot position, with full

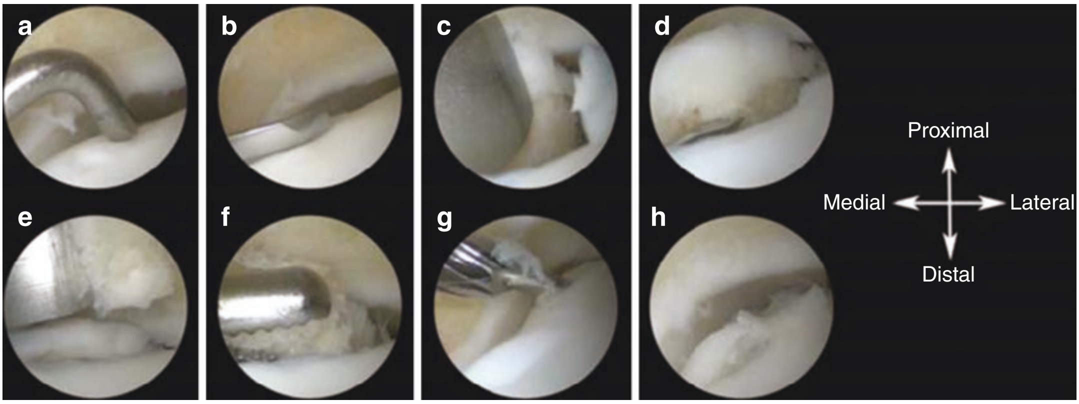

Fig. 41.3 Arthroscopic images of the lift, drill, fill and fix (LDFF) procedure performed on a medial osteochondral lesion of the left talus. **(a)** The cartilage is palpated with a probe to identify the exact location of the talar OCD, while the ankle is in plantarflexion. **(b)** By means of the beaver knife, the orthopaedic surgeon creates an osteochondral flap. **(c)** The flap is lifted by a chisel (lift). **(d)** While taking care not to loosen the iatrogenically created osteochondral fragment at its posterior side, the bony flake of the fragment is drilled with a Kirschner wire and a shaver blade in order to promote revascularization (drill). **(e)** A 4 mm chisel is used to harvest cancellous bone from the distal tibial metaphysis. **(f)** Subsequently, the cancellous bone harvest is transported into the defect by means of an arthroscopic grasper until one achieves adequate filling (fill). **(g)** To prepare for the fixation step, a cannulated system is used to allow a predrilling and tapping of a compression screw. **(h)** The orthopaedic surgeon places an absorbable screw 1 to 2 mm recessed relative to the surrounding hyaline cartilage surface. Because of its diameter and substantial compression strength, a noncannulated screw is of preference (Figure reproduced from Reilingh and Kerkhoffs (2015))

weight bearing allowed. At 8 weeks postoperatively, the cast is removed. Physical therapy is started to assist in functional recovery and extend to full weight-bearing in approximately 2 weeks. The objective is to adhere to an appropriate personalized after-treatment in which it is key to focus on proprioception, balance, ankle functionality, in order to work towards a normal ambulation pattern, achieve full strength and, then optionally, depending on the patient, running, and sport-specific training. Subsequent to this, return to sport can be planned.

41.9 Osteochondral Fragment Fixation: Results

In 2014, a retrospective case series was published on nine children after an internal open fixation with a median follow-up of 4 years (Reilingh et al. 2014). A good outcome score was reported in 78% of the cases, and the median postoperative American Orthopaedic Foot and Ankle Society (AOFAS) score was 95 (Berndt and Harty 1959; Kitaoka et al. 1994). No progressive degenerative changes on final follow-up radiographs were observed. Other studies have reported on the outcome after an open fixation procedure in adults (Kumai et al. 2002; Schuh et al. 2004). Kumai et al. (2002) reported an excellent success rate of 89% for the fixation with bone pegs of large, loose fragments in 27 patients with a mean follow-up of 7 years. Thirteen of the fourteen patients (93%) engaged in sporting activities prior to surgery were able to resume these activities postoperatively. In a retrospective case series of 20 patients, Schuh et al. (2004) reported a 100% success rate after a mean follow-up of 46 months.

When analysing the results of the arthroscopic LDFF procedure, a recent publication reports the short-term clinical outcomes for seven patients with primary talar OCDs at a mean follow-up of 12 months (Kerkhoffs et al. 2016). In all patients LDFF led to significant improvements in the AOFAS and numeric rating scales (NRS) of pain at rest and during walking (Salaffi et al. 2007). All seven patients indicated that they were satisfied and that they would undergo the same surgery again. Radiologically, it became clear that on the final radiographs at 12 months postoperatively, five of the seven patients showed remodelling and progressive bone ingrowth (Fig. 41.2b). Although these clinical and radiological results indicate that a minimally invasive arthroscopic “Lift, Drill, Fill and Fix” procedure for primary talar OCDs is a promising intervention, longer follow-up times are needed. Additionally, more patients need to be included for a larger statistical power, and it is of paramount importance to investigate the arthroscopic LDFF procedure in a prospective comparative randomized manner. Nonetheless, it is of clinical relevance to realize that in case of failure after an open or arthroscopic fixation procedure, other surgical procedures, such as BMS, are still to be regarded as options of choice.

41.10 Minimally Invasive Replacement Surgery for Talar OCDs after Failed Primary Surgery

Arthroscopic BMS and fixation techniques are considered to be optimal for treating primary osteochondral defects of the talus. However, if the desired restoration of the articular cartilage and its subchondral bone fail in combination with persisting ankle symptoms, more extensive surgical procedures should be considered. For treating these challenging defects, one can, again, adhere to one of the other four postulations of O’Driscoll (1998), namely, that damaged or lost articular cartilage can be replaced, instead of restored. An adequate shared decision-making process should be initiated to determine an appropriate surgical intervention (Lambers et al. 2018). Surgery after failed prior surgical treatment is generally less minimally invasive as more aggressive types of surgical interventions are administered, such as osteochondral autologous transplantation systems (OATS), mosaicplasty, osteochondral allograft transplantations and matrix-induced autologous chondrocyte implantation (MACI) techniques. These treatment strategies except for the latter are conventionally performed in an open manner, as the talar OCD is reached via medial or lateral osteotomies and plafondplasties.

41.11 Arthroscopic Cartilage Transplantation: Technique and Results

Matrix-associated autologous chondrocyte implantation (MACI) techniques and autologous chondrocyte implantation (ACI) techniques are similar cartilage transplantation techniques. However, when explaining the general technique, it should be mentioned that the arthroscopic MACI procedure differs slightly from the classic arthroscopic ACI procedure in terms of surgical technical details. Both techniques consist of two steps, and during the first stage, the surgeon assesses the talar OCD via the anterolateral and anteromedial portals and evaluates the status of the articular cartilage and its underlying bone. The lesion is accurately shaved and the diseased tissue removed, after which the chondrocytes are either harvested from the margin of the lesion, from the anterior margin of the tibia or from a potentially detached osteochondral fragment. The harvested chondrocytes are then expanded in a laboratory, and subsequent to this, these are seeded on a hyaluronic acid scaffold. When performing the second-generation autologous chondrocyte implantation technique (MACI), the harvested chondrocytes will be cultured and seeded on a bioabsorbable, porcine type I/III collagen scaffold for 1–3 days. After the expansion, the second-step arthroscopic procedure occurs. In the ACI procedure as described by Giannini et al. (2008), the second-step arthroscopy consists of ACI implantation via specifically designed instrumentation (Citieffe, Calderara di Reno, Bologna, Italy). Inserted via the same arthroscopic portals is a stainless steel cannula with a window on one side and a positioner on the other side so that the scaffold can be delivered to the lesion. After having filled the defect with the engineered biomaterial consisting of the harvested chondrocytes, the scaffold was made to fill the lesion. For the second step of the arthroscopic MACI procedure, as described by Aurich et al. (2011), the matrix is inserted with arthroscopic forceps and subsequently placed onto the defect, after which it is sealed with fibrin glue.

The first report was a prospective case series describing a completely arthroscopic autologous chondrocyte implantation procedure in the ankle joint, published by Giannini et al. (2008). In this study, 46 patients underwent surgery, of which 16 were previously operated on with treatments such as BMS or mosaicplasty. At a mean follow-up of 36 months, the mean AOFAS score was 87, and the histological evaluations of the biopsies highlighted the presence of all the components of hyaline cartilage. A more recent study on arthroscopic ACI by the same author group showed similar clinical results at midterm follow-up of 87 months, and it was observed that the failed implants included in this patient group demonstrated fibrocartilaginous tissue (Giannini et al. 2014). However, this study might have included the same patients as were analysed in the publication of 2008. The arthroscopic MACI procedure was researched in a publication by Aurich et al. (2011), and of the 18 patients that were included, there were 19 talar OCDs, of which 11 cases had had prior surgical treatment consisting of either (arthroscopic) BMS, prior ACI or an open reduction internal fixation due to an ankle fracture. The arthroscopic MACI yielded a success rate of 64% according to the AOFAS scale, and at a mean follow-up of 25 months, 56% of the patients were able to return to sports at the same level as preoperatively. Although it appears that successful results are achieved by means of an arthroscopic first- or second-generation autologous chondrocyte implantation technique, it should be noted that disadvantages of the MACI are the high costs, the complexity of the technique, and, in most cases, the need for two surgical procedures.

41.12 Minimally Invasive Osteochondral Transplantation Procedures

Earlier in the chapter, we described the procedure of retrograde drilling. However, in case of advanced subchondral lesions with or without the existence of a (large) subchondral cyst, the surgeon may choose to insert a retrograde autologous cancellous bone plug in addition to retrograde drilling. A study of nine patients who underwent arthroscopic retrograde cancellous bone plug transplantation (harvested from the ipsilateral iliac crest) revealed that all patients had nearly normal International Cartilage Repair Society (ICRS) scores at 1-year post-surgery as assessed by second-look ankle arthroscopy (Smith et al. 2005).

Osteochondral autograft transfer systems (OATS) are also performed when treating large, cystic lesions, after failed prior surgical treatment. When performing the classic OATS procedure, the talar OCDs are reached after having arthroscopically assessed the talar lesion either via malleolar osteotomies or via plafondplasties. In order to perform this open treatment less invasively, different surgical techniques have been developed (Largey et al. 2009; Sasaki et al. 2003). The studies reported here utilize an OATS procedure using a transmalleolar approach. The technique consists of harvesting the osteocartilaginous grafts from the ipsilateral femoral condyle or the lateral trochlear edge, after which they are inserted into the posteriorly located defects via a transmalleolar bone tunnel subsequent to the completion of transmalleolar drilling guided by a pin. From the study of Largey et al. (2009) including limited numbers of patients and Sasaki et al. (2003), it can be concluded that an osteochondral autograft procedure with a transmalleolar approach is technically feasible. Three out of five patients showed good to very good results, while the other two patients complained of donor-site morbidity or functional deterioration of the ankle (Largey et al. 2009). The advantages of this surgical approach are that it is less invasive than a lateral or medial malleolar osteotomy and that compared with the classic OATS procedure, earlier range of motion exercises and weight-bearing is permitted. The disadvantages are the secondary donor-site morbidity associated with the harvesting procedure and the complexity of the procedure due to the positioning of the transmalleolar bone tunnel. Comparative studies are of paramount importance to assess the clinical advantage and efficacy of this new surgical technique.

41.13 Conclusion

Adequate management of OCDs of the talus is still a challenging concern and raises daily questions in the clinics. Current practice consists of non-surgical management and/or a surgical modality. Determining the most appropriate surgical modality for the individual patient depends on a high number of (prognostic) factors such as lesion size, location and stage, primary surgical management or failed previous surgery, age of the patient and acute or chronic nature and displacement, and therefore, a high number of surgical treatment strategies are currently practiced in order to tackle the (combination of) individual factors. In this chapter, an insight into the historical perspective of talar OCDs was provided, and a critical update on the non-surgical management and minimally invasive surgical treatment for primary osteochondral defects and those that had failed prior surgical treatment was presented. Additionally, a promising minimally invasive internal fixation treatment strategy, the arthroscopic “Lift, Drill, Fill and Fix” (LDFF) procedure was described.

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Talar Neck Fractures

42

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42.1 Anatomy

The talar bone (talus) is the second largest tarsal bone, and because of its multiple articulations, it is mainly covered by articular cartilage (Coltart 1952). Talar fractures are uncommon, accounting for less than 2.5% of all fractures and usually are a result of high-energy trauma (Canale and Kelly 1978; Fournier et al. 2012; Lin and Hak 2011; Vallier et al. 2003).

The talus has a unique anatomical shape and function. It is called "the bony meniscus" and one of the only body parts in the human body without any direct muscle attachments (Canale and Kelly 1978). Basically, it provides the junction between the lower leg and the midfoot.

The talus contributes to three essential joints of the foot: tibiotalar, talonavicular, and subtalar. The vast majority of talar fractures are either intra-articular or lead to a joint incongruity by extra-articular axial displacement. Because of its strong subchondral bony cortex, considerable forces are needed to produce a talar fracture. Consequently, many of those injuries occur in patients who have sustained multiple injuries. The high variability of talar fractures, their relatively low incidence and the high percentage of concomitant injuries, often makes the treatment of these injuries a major challenge.

The talus is composed of three parts, head, neck, and body, and it also has two processes: the lateral and posterior talar process. The frontal part consists of the talar head, and it articulates mainly with the navicular bone. The body of the talus incorporates the dome of the talus at the ankle joint and the posterior facet at the subtalar joint. The neck that sits over the sinus tarsi consequently connects the talar body with the talar neck.

About two thirds of the talus is covered with articular cartilage, leaving only the area around the talar neck and the posterior aspect of the body capable of receiving periosteal blood supply. The talar trochlea is broader anteriorly and inferiorly than posteriorly and superiorly (Fig. 42.1). The lateral joint facet to the fibula is broader and deeper and has a higher slope than the facet articulating with the medial malleolus.

The talar neck is one of the few parts of the talus that is not covered by any articular cartilage, and it is the area of the talus that is most vulnerable to fracture. It has four surfaces: superior, inferior, lateral, and medial. It is surrounded posteriorly by the talar dome and anteriorly by the talar head's articular surface. Laterally, the medial portion of

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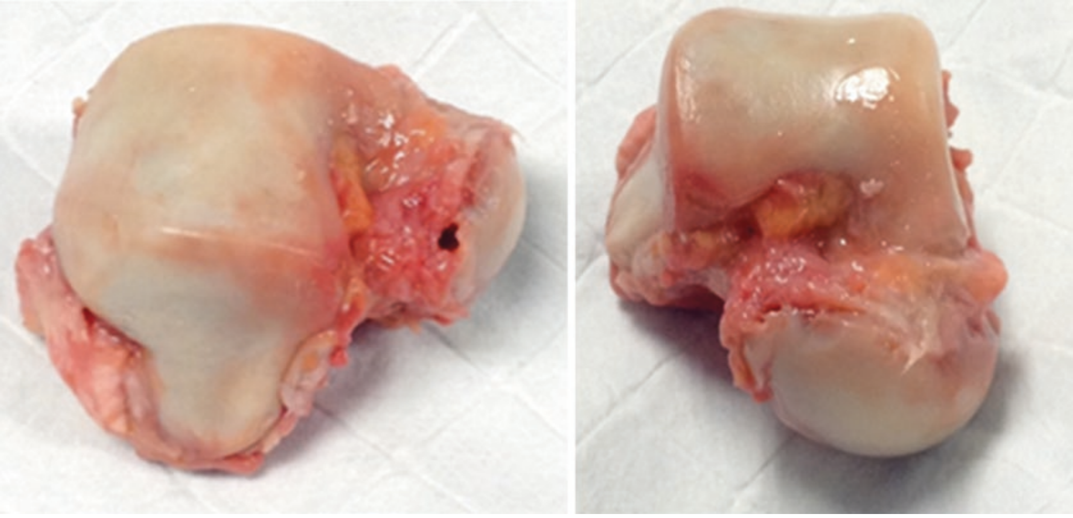

Fig. 42.1 Lateral and anterior cadaveric talar bone view. Photo Copyright: Dr. Pieter D'Hooghe (Chapter corresponding author)

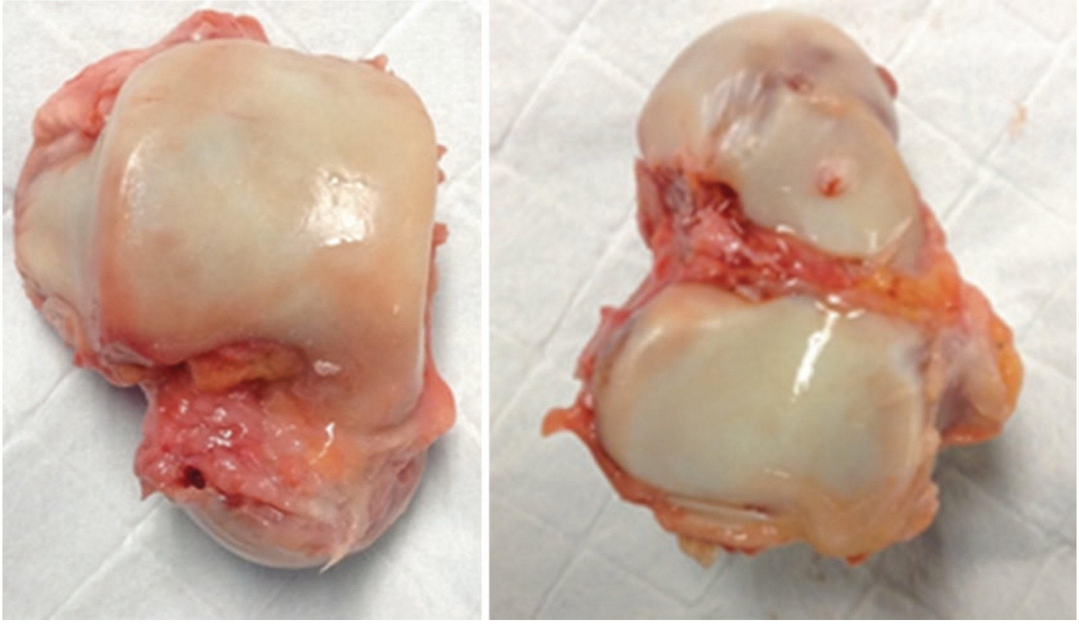

Fig. 42.2 Superior and Inferior cadaveric talar bone view. Photo Copyright: Dr. Pieter D'Hooghe (Chapter corresponding author)

the inferior extensor retinaculum inserts onto the talar neck. Inferiorly, it serves as a roof to the sinus tarsi and stabilizes the subtalar joint by hosting the insertion to the talocalcaneal ligament. Medially, the talonavicular ligaments insert into its slightly convex surface. In the horizontal plane, the neck of the talus shifts medially in reference to the talar body. The amount of medial deviation is variable and can range from 10 to 44° with an average of 24° (Daniels and Smith 1993). In the sagittal plane, a broad range in deviation can occur, from 5 to 50°, average 24° (Daniels and Smith 1993). Taken together, the wide variation of angulation in normal values makes radiographic interpretation of talar neck fractures sometimes difficult (Fig. 42.2).

The vascular supply to the talus enters via five main access routes: through the superior and inferior surface of the neck, the anterolateral and medial surface of the body, and the posterior tubercle (Daniels and Smith 1993). The talar neck and head are supplied by periosteal branches of the dorsalis pedis and peroneal arteries, and consequently, that makes them less vulnerable with respect to AVN.

42.2 Mechanism of Injury

About half of talar fractures occur because of a fall from a height. The other half is related to high-energy trauma such as motor vehicle accidents. Less than 10% of talar neck fractures result from an indirect force (Tscherne and Schatzker 1993). A high percentage of patients who sustain a talar fracture are polytraumatized, having sustained multiple injuries (Rammelt et al. 2005). Talar neck fractures comprise approximately 45% of all talar fractures and are produced by decelerating forces with axial impaction (Rammelt et al. 2005, Fig. 42.3). According to biomechanical studies, the talus acts as a cantilever between the tibia and the calcaneus, and the calcaneal sustentaculum tali acts as a lever arm, while the foot is in dorsiflexion (Peterson et al. 1976).

If the energy of trauma is not adequately absorbed, the talar body is extruded posteriorly with the deltoid ligament serving as a hinge and

Fig. 42.3 Talar bone dislocation with a combined talar neck fracture avulsion. Initial closed reduction was achieved and stabilized by percutaneous temporary Kirschner wires, one anteriorly through the talonavicular joint, and one posteriorly through the talocalcaneal joint. Photo Copyright: Dr. Pieter D'Hooghe (Chapter corresponding author)

providing the last resort of blood supply (Rammelt and Zwipp 2009). With the foot in plantar flexion, the more variable talar body fractures are produced by the same mechanism. Sagittal fractures of the talar dome appear to result from shearing forces (Sneppen et al. 1977).

42.3 Clinical Assessment

Talar neck fractures are clinically evident with swelling and hematoma over the ankle region. Range of motion testing at the ankle, subtalar, and midtarsal joint is painful and restricted. Patients are unable to bear weight on the affected foot. With fracture dislocations (Fig. 42.4), the ankle displays a marked deformity with pale skin over the prominent bone fragments, rapid blistering and subsequent skin necrosis development.

The foot is examined for neurovascular status. If the foot pulses are not palpable, the tibialis posterior and dorsalis pedis arteries should be evaluated using Doppler ultrasound. In unconscious patients with critical soft tissues, compartment syndrome must be ruled out by intramuscular pressure measurements. Associated soft tissue trauma is common in talar neck fractures. Open fractures occur frequently, accounting for 20–25% of injuries, with greater incidence as fractures become more displaced (Lindvall et al. 2004; Vallier et al. 2004a). Open wounds are inspected in the operating room, and urgent surgical assessment should be undertaken. Care must be taken not to overlook talar fractures in multiply injured or polytraumatized patients (Rammelt et al. 2005). Closed injuries also are usually associated with severe swelling and deglovement injury due to the high-energy nature of the trauma.

Fig. 42.4 Clinical presentation of an acute talar neck/body fracture dislocation. Photo Copyright: Dr. Pieter D'Hooghe (Chapter corresponding author)

42.4 Imaging

Standard radiographic projections for a suspected talar neck fracture include an anteroposterior and lateral view of the ankle. The talonavicular joint is best assessed radiographically through a dorsoplantar view of the foot with the tube tilted 20° caudally (Suren and Zwipp 1986). Malalignment of the subtalar joint and fractures of the lateral process can be detected with a 20° *Brodén view*. Talar neck axial deviation can be assessed by the *Canale view* with the foot pronated 15° and the tube tilted 45° caudally (Canale and Kelly 1978).

These specific projections have, however, lost much of their importance due to the generous use of computed tomography (CT) scanning in cases of talar fractures. If a talar fracture is suspected, a CT scan with coronal, axial, and sagittal reconstruction is performed to rule out a minimally displaced fracture or minor step-off in the affected joint(s). If a talar neck fracture is observed in standard radiographs, a CT is essential for more precise fracture assessment and classification of the fracture and preoperative planning. MRI appears to be overall less indicated in talar neck fractures but can be very helpful in identifying edema or stress reactions (Fig. 42.5).

Fig. 42.5 Sagittal and axial T2 MRI images indicating posttraumatic edema and stress reaction in the talar neck. Photo Copyright: Dr. Pieter D'Hooghe (Chapter corresponding author)

42.5 Classification

Talar neck fracture classification is challenging due to the high variability in fracture patterns and presentation. Easy-to-use classifications may comprise too many different fracture types into one group, while more extensive classifications are difficult to use in daily practice and have a low inter-observer reliability. CT scan is helpful to identify minimally displaced fractures and to diagnose small process fractures that otherwise would go unnoticed on plain radiograph viewing. CT scan is also indicated to accurately differentiate between talar neck and body fractures. In the sagittal plane, talar neck fractures can run through the sinus tarsi (Inokuchi et al. 1996). Fractures of the talus have been classified by Hawkins (1970) and Marti (1974) with respect to the degree of initial dislocation and the number of affected joints.

The most commonly used talar neck fracture classification is the one by Hawkins (1970) that pertains to the most frequent talar neck fracture presentation. Type IV was added later by Canale and Kelly (1978).

According to Hawkins (1970), there are four types of talar neck fractures:

Type I: Non-displaced
Type II: Dislocation at the subtalar joint

Fig. 42.6 Sagittal T1 MRI image of a non-displaced (Hawkins type I) fracture of the neck of the talus with adjacent bone edema. There are small foci of subchondral bone edema in both sides of posterior subtalar joint. There is also talonavicular and tibiotalar joint effusion. Photo Copyright: Dr. Pieter D'Hooghe (Chapter corresponding author)

Type III: Dislocation at the subtalar and tibiotalar joints
Type IV: Dislocation at the subtalar, tibiotalar, and talonavicular joints

Type I fractures (Fig. 42.6) are non-displaced, and the talar body maintains the normal relationship with the ankle and subtalar joint. The fracture line runs between the anterior and middle facets of the subtalar joint. This fracture type can be easily missed since the fracture line is frequently parallel to the radiographic beam on the lateral view. This fracture type only disrupts vessels entering the dorsal and lateral aspects of the talar neck, so the risk for AVN is considered minimal, ranging from 0% to 10% (Thordarson et al. 1996).

Type II fractures are displaced fractures of the talar neck with subluxation or dislocation of subtalar joint. The subtalar dislocation can occur medially (more common) or laterally. If the subtalar dislocation is complete, these injuries are often open because of the thin subcutaneous soft tissue. In type II fractures, the relationship of the talus within the ankle joint is normal, the talar head retains its normal relationship with the navicular bone and with the anterior facet of the subtalar joint. This fracture type disrupts the dorsal and lateral vessels but also disrupts vessels coming from the vascular sling that runs under the talar neck. In these fractures, the AVN risk ranges from 20% to 50% (Thordarson et al. 1996).

Type III fractures are displaced talar neck fractures with dislocation of the subtalar and ankle joints. The talar body is often extruded posteromedially between the posterior surface of the tibia and the Achilles tendon. The relationship with the navicular bone in type III fractures is normal. More than 50% of these type III injuries represent open fractures (Daniels and Smith 1993). Here, the talus blood supply is severely disrupted except the vessels arising from the deltoid branches. These fracture types present with a very high AVN risk, ranging from 80% to 100% (Canale and Kelly 1978).

Type IV fractures were added by Canale and Kelly (1978). In type IV injuries, talar neck fractures are associated with dislocation of the talar body from the ankle and subtalar joints, in combination with a talar head dislocation from the talonavicular joint (Hawkins 1970). As in type III fractures, these injuries account for a high AVN risk.

Marti (1974) introduced an easy-to-use fracture classification system that considers talar neck and body fractures as well as "peripheral" fractures of the talar processes:

Type I: Fractures of the "distal" talar neck (including talar head and process fractures)
Type II: Non-displaced "proximal" talar head and body fractures
Type III: Displaced talar neck and body fractures
Type IV: Talar neck and body fractures with talar body dislocation out of the ankle mortise

The Orthopaedic Trauma Association (OTA) classification distinguishes between extra-articular fractures (Type A), partial intra-articular fractures (Type B), complete intra-articular fractures including crush injuries (Type C), and pure ligamentous dislocations termed as Type D (Marti 1974). Type A also comprises talar process fractures which are almost always intra-articular, while flake fractures are classified as Type B. Subgroups refer to the fracture mechanism and distinguish between simple and complex fractures. Clinical studies so far have not demonstrated a prognostic relevance by the use of this classification system (Vallier et al. 2003, 2004a).

42.6 Indications and Contraindications

To prevent severe damage to the soft tissues and preserve the blood supply to the talar neck and body, all dislocated talar neck fractures (Hawkins types III–IV, OTA Type C) need to be reduced immediately. Closed or percutaneous reduction under sufficient analgesia and relaxation should be attempted. If closed reduction fails (due to a locked dislocation position or soft tissue interpositioning), urgent conversion to open reduction and fixation is mandatory.

If definitive internal fixation is impossible (e.g., polytraumatized patients, lack of experience with complex fractures), an approximate reduction may be achieved with direct, limited incisions and preliminarily secured with Kirschner wires (K-wires) (Fig. 42.3). Anatomic reduction and definite stable osteosynthesis may be carried out at a later stage under ideal conditions (Rammelt et al. 2005). In case of an open fracture, primary operative treatment is generally indicated (Sanders et al. 1992). If a patient presents with a diagnosis of foot compartment syndrome, a dorsomedial skin incision and fasciotomy (including the superior and inferior extensor retinacula) is urgently indicated. This approach can also be used for fracture reduction and fixation. In the presence of severe combined soft tissue damage, internal fixation can be supplemented with tibio-metatarsal external fixation in order to protect the soft tissues from further damage and to allow for clinical monitoring.

Displaced talar neck fractures should be treated as early as possible by anatomical open reduction and stable internal fixation. Immediate treatment may not be feasible because of limited local resources or the lack of experience with these rare and variable injury types. Surgeons can feel uncomfortable with treating displaced talar neck fractures (Hawkins type III) at any time, but surgery should be performed within 24 h of the injury (Patel et al. 2005).

Treatment of all minimally displaced talar neck fractures (Hawkins type II) should initially be delayed until ideal conditions can be provided. In select cases, fractures that show no displacement (Hawkins type I) on CT scan may be treated non-operatively in selected cases.

Still, after non-operative treatment in undisplaced talar neck fractures, there is a relatively high posttraumatic arthritis rate which could indicate the value of percutaneous or mini-open surgical approaches even in these fracture types (Lindvall et al. 2004; Lutz et al. 1998).

Primary ankle or subtalar joint arthrodesis is indicated only in exceptional cases of comminuted fractures with articular surface destruction in order to preserve as much foot function as possible (Thomas and Daniels 2003). Contraindications to open reduction and internal fixation include soft tissue infections, chronic venous insufficiency with skin ulceration, advanced peripheral vascular disease, immunodeficiency, and noncompliant patients.

42.7 Preoperative Planning

Optimal treatment relies on the accurate preparation and understanding of the talar fracture type and pattern. Plain radiographs should be obtained initially to characterize the talus fracture and to identify possible adjacent injuries. CT scans are very helpful in the diagnostic and preoperative setup and for follow-up (Williams et al. 2012). As discussed, preoperative vascular and soft tissue assessment is also crucial prior to any intervention.

42.8 Treatment

Non-operative management can be considered for non-displaced talar neck and body fractures (Hawkins type I, OTA Type A) in non-ambulatory patients or in patients with comorbidities that don't allow them medically to tolerate surgery. Indications for non-operative management occur very rarely. Splinting followed by short leg casting for a period of several weeks (approximately 8 weeks) until fracture union is advised. Fractures of the talar neck that are completely non-displaced on CT scan can be treated in a cast with the foot in neutral position for a period of 6 weeks. Patients are allowed to partially weight-bear on the affected leg for only 20% of their total body weight (plantar touch). Full weight-bearing will be allowed at the time of complete radiographic union, usually after 8–10 weeks.

The current standard of care for talar neck fractures with any displacement is open reduction and internal fixation (ORIF). If open reduction is contraindicated (local or general contraindications) in fracture dislocations or severely displaced talar neck fractures, closed reduction under complete relaxation of the patient can be attempted (Zwipp 1994), (Fig. 42.3). For displaced talar neck fractures, the forefoot is brought first into hyper-dorsiflexion followed by forced plantarflexion under an axial force with a concomitant downward "pull" on the heel. The latter may be facilitated with a Schanz screw introduced perpendicularly into the calcaneal tuberosity. The treating physician has to consider that every unsuccessful attempt at closed reduction increases the damage to the already compromised soft tissues and the overall complication rate.

Screw fixation for non-displaced talar neck fractures (as verified on CT scan) aims at compression across the fracture in order to prevent re-dislocation and allows for earlier range of motion tolerance. Screw fixation can be performed with minimal posterolateral or anteromedial incisions. Two Kirschner wires are introduced across the fracture to prevent secondary dislocation, while definitive fixation is being performed. If cannulated screws are indicated, it is recommended to use a complementary minimum of two stabilizing guide wires to prevent fracture displacement or rotation during the fixation process (Cronier et al. 2004).

Open talar fracture injuries are treated as an emergency, according to the general principles of open fracture treatment. After copious lavage, all contaminated and avascular tissue is debrided. Fracture reduction is achieved through bilateral surgical approaches (posterolateral and anteromedial), including the open wound in the incision when possible.

Ideally, a standard osteosynthesis is primarily performed. If primary anatomic reduction and fixation is not possible (as in polytraumatized patients or patients with complex deglovement trauma), gross reduction should be secured with K-wire fixation. In patients with severe combined soft tissue damage, a tibio-metatarsal external fixator can be applied for initial stabilization.

If primary wound closure after debridement is not possible, artificial skin graft for wound closure may be temporarily applied. Early definitive soft tissue coverage and stable internal fixation is mandatory to prevent infection and allow for functional rehabilitation. The type of soft tissue closure is determined by a second-look intervention that should ideally be planned within 48–72 h after the first surgery. Alternative options include secondary direct suture, skin grafting, local flaps (sliding or rotational), and/or use of free microvascular flaps (Brenner et al. 2001; Sanders et al. 1992).

42.9 Surgical Technique

Both anteromedial and anterolateral surgical approaches are recommended to optimize access to the talar neck and the anterior part of the talar body (Fournier et al. 2012; Gonzales et al. 2011; Smith and Ziran 1999; Vallier et al. 2004b; Van Bergen et al. 2011; Ziran et al. 2001). Although the usage of combined surgical approaches has never been shown to increase the risk for osteonecrosis, dissection of the inferior aspect of the talar neck should be avoided to protect the remaining vital talar blood supply (Smith and Ziran 1999; Vallier et al. 2004b; Van Bergen et al. 2011; Ziran et al. 2001). The deltoid ligament should not be violated for the same reason. Ipsilateral medial malleolar fractures occur frequently in combination with this pathology and may facilitate visualization of the medial talar body through the fracture site, as the fractured malleolus can be reflected inferiorly (Fournier et al. 2012; Gonzales et al. 2011; Smith and Ziran 1999; Vallier et al. 2004b; Van Bergen et al. 2011; Ziran et al. 2001).

The classic approach for displaced talar neck fractures is the anteromedial approach. For talar body fractures, the incision may be extended proximally (broken line) and a medial malleolar osteotomy can be added. The skin incision begins over the medial malleolus and extends in a curved manner distally to the navicular tuberosity. This incision lies halfway between the tibialis anterior and tibialis posterior tendon in a relatively safe zone with respect to potential neurovascular damage. Care must be taken not to dissect the deep portion of the deltoid ligament which is carrying an important arterial blood supply to the talar neck.

Talar neck fractures can be assessed from the medial aspect after longitudinal dissection of the superficial tibio-navicular and talonavicular ligaments. However, for anatomic reduction purposes, it is advised to consider a second approach from the lateral side to minimize the chances of malrotation or axial malalignment of the talar head fragment. The lateral approach is either carried out as a curved incision starting at the lateral malleolus *(anterolateral approach)* or running obliquely along the skin crests over the sinus tarsi in front of the lateral malleolus (Ollier's approach). When using a lateral approach, the course of the peroneal tendons and the superficial peroneal nerve has to be respected. The inferior extensor retinaculum is dissected, and the extensor digitorum brevis muscle is retracted.

After talar neck reduction from the *medial* side, anatomical reduction and congruity of the subtalar joint can be verified through the *lateral* approach. If a fracture gap is observed laterally, a varus deformity or malrotation of the talar neck needs to be corrected. Temporary fixation is achieved with a minimum of two K-wires introduced from the talar head close to the talonavicular joint surface into the talar body. Reduction quality is controlled using intraoperative fluoroscopy in three projections (anteroposterior and lateral ankle views and a dorsoplantar view of the foot). After anatomical reduction is assured, the K-wires are replaced by small fragment screws (3.5–4.0 mm). The anteroposterior screw positioning is generally preferred although posteroanterior screw position is shown to provide increased stability in biomechanical trials (Swanson et al. 1992, Fig. 42.7).

To achieve maximum fixation stability, the screws are introduced and advanced all the way toward the posterior part of the talar body. They should not be positioned too close to the sinus tarsi area in order to preserve the remaining talar body blood supply (Lemaire and Bustin 1980). If the screws have to be inserted near the talonavicular joint surface, care must be taken to countersink the screw heads adequately below the articular cartilage to avoid joint irritation upon weight-bearing. On the lateral aspect of the talar neck, the fracture often leaves a cortical bone spur that can be used for screw fixation (Cronier et al. 2004).

In the presence of medial talar neck comminution, use of a screw lagging technique must be avoided to not risk shortening or creating a varus deformity. If there is any extensive comminution on the medial part of the talar neck, a small plate (2.0–2.7 mm) can be added or used for stabilizing the medial wall (Fleuriau Chateau et al. 2002). Also, to enhance stability, screws are better inserted in a convergent manner both medially and laterally (Sangeorzan et al. 1992).

Fig. 42.7 Preoperative and postoperative coronal CT scan view of a comminuted talar body fracture with extension of the fracture line to the subtalar and tibiotalar articulations. Photo Copyright: Dr. Pieter D'Hooghe (Chapter corresponding author)

42.10 Arthroscopic Treatment of Talar Neck Fracture

The use of ankle arthroscopy as added value in the treatment of talar fractures has recently been popularized although its effectiveness remains to be proven. Anatomical reduction and stable fixation remain the two major objectives in the successful management of talar fractures. By adding an arthroscopically assisted technique to the ORIF procedure, this allows the surgeon to have an improved overview on the intra-articular fracture status. Moreover, arthroscopy reduces the risk of avascular talar necrosis since it prevents further soft tissue damage in an area that already suffers from compromised vascularization. The anatomical reduction and fracture congruency can be verified by arthroscopic viewing of both the tibiotalar and subtalar joints under fluoroscopic control of during the procedure.

42.11 Operative Technique

The arthroscopy can be carried out under general or regional (spinal) anesthesia. A fluoroscopic C-arm can be added to support critical procedural steps. Traction may or may not be used. Conventional anteromedial (AM) and anterolateral (AL) portals can be used after marking the cutaneous peroneal nerve branch. Two lateral subtalar portals can be added to these primary portals where required. The first subtalar (lateral subtalar) portal is placed 1 cm inferior and anterior to the lateral malleolus tip. The second subtalar (accessory subtalar) portal is best placed under direct arthroscopic visualization. Subtalar joint exploration and debridement can then be achieved through these two subtalar accessory portals. The integrity of the tibiotalar joint and potential additional lesions is best viewed with the arthroscope in the anterolateral portal. Fracture reduction is best achieved through the first subtalar portal while keeping the arthroscope in the anterolateral portal. Two divergent K-wires are used for temporary fracture fixation as described in the open technique. When adequate fracture reduction and stabilization is achieved, two 4.5 mm cannulated, partially threaded cancellous screws are put in position to optimize compression over the fracture. Subtalar joint surface congruency can be evaluated best through the first subtalar portal, and in case of any remaining small osteochondral fragments or loose bodies, the surgeon can decide at that time whether to fix or to excise them.

A short lower-leg cast is normally applied postoperatively for 4–6 weeks. After this initial period, a walking boot is administered to allow progressive partial weight-bearing. Passive- and active-assisted ankle range of motion can be started when the patient is clinically ready and when radiological evaluation confirms acceptable fracture healing. Full weight-bearing is normally not indicated before 2–3 months postoperatively.

An arthroscopic-assisted technique offers many advantages such as enhanced visualization on the anatomical restoration of the ankle joint and control of ankle (and subtalar) joint surface congruency. This technique may lead to fewer postoperative complications over the soft tissues and can protect the already compromised vascularization in the fracture area. Although this type of surgery requires advanced surgical experience, there is a clear evolution in its indications because of the aforementioned advantages added to the classic open procedure.

42.12 Pearls and Pitfalls

Although talar fractures are rare, they are associated with debilitating complications and potential functional limitations. Urgent reduction of associated dislocations is recommended with ORIF for displaced fractures while respecting the adjacent soft tissues. Restoration of articular surface congruency and axial alignment is mandatory in order to regain optimal posttraumatic ankle and hindfoot function. In talar neck fracture surgery, it is recommended to always use two incisions (anteromedial and anterolateral). This allows for improved fracture visualization and reduction status.

It is advised to avoid any unnecessary soft tissue dissection around the neck of the talus that would further compromise vascularization. If anatomical reduction cannot be achieved, this may lead to severe disability with a stiff foot, positioned in varus and supination. In Hawkins type III fractures with a displaced central talar body, it can be indicated to add a medial malleolar osteotomy to the initial approach. Further, it may be valuable to use non-compressive titanium fixation (to avoid compressing the comminuted bone) and to prepare for adding a small metallic plate along the lateral neck and body of the talus.

42.13 Postoperative Management

Treatment goals include restoration of the articular fracture surface and axial alignment followed by rigid fixation to maintain stability until fracture union. Ideally depending on bone quality, integrity of the fixation, and soft tissue status, early range of motion exercises should be initiated to minimize posttraumatic stiffness. Early motion helps restore critical joint function. Postoperatively, a below-the-knee cast is applied along with strict leg elevation guidelines. Range of motion exercises and continuous passive motion (CPM) can sometimes be considered on the second postoperative day. If external fixation is applied, it should be maintained until adequate soft tissue healing occurs. Depending on the fracture type, degree of bone quality, and fracture comminution, it may take at least 2 months for full weight-bearing to be allowed. Temporary K-wires are usually removed after 6 weeks postoperatively. Screws or plates should be removed at a later stage only if proven symptomatic.

42.14 Results and Complications

Because of the nature of this injury, talar neck fractures may present with both early and late complications. Early complications are mainly related to soft tissue problems, such as insufficient wound healing or infection. The early complication rate can be reduced by urgent closed or open reduction, administration of antibiotics, surgical debridement for open fractures, and meticulous soft tissue handling intra-operatively (Lack et al. 2015). Definitive treatment is usually deferred until swelling has resolved, approximately between 1 and 2 weeks post-injury (Mayo 1987; Vallier et al. 2004b). Infections occur predominately following open talar neck or body fractures (Vallier et al. 2003, 2004a, b).

Some authors discriminate between superficial (wound infections) and deep soft tissue infections or osteomyelitis, but the overall infections rates range between 3% and 8% (Elgafy et al. 2000). While superficial wound edge necrosis usually heals with relative rest and antiseptic dressings, deep soft tissue infections require radical debridement of all infected and necrotic tissue, lavage, occasionally hardware removal, external fixation, continuous drainage, and parenteral administration of antibiotics.

The most dreaded complication is septic necrosis of the talar body requiring partial or total talectomy and secondary tibio-calcaneal fusion (Rammelt et al. 2001). If combined soft tissue reconstruction is indicated, skin grafting is generally required (Vallier et al. 2003, 2004a, b). The most common *late* complications are nonunion (or malunion), AVN or osteonecrosis, and post-traumatic arthrosis.

Nonunion is infrequent and occurs in less than 5% of talar neck fracture cases (Elgafy et al. 2000; Halvorson et al. 2013; Xue et al. 2014). In previous reports the incidence of malunion varies between 0% and 37% and is likely underestimated due to limitations in the ability to assess articular and axial malalignment using plain radiography (Halvorson et al. 2013; Xue et al. 2014). Malunions can be seen predominately in previously overlooked fractures, non-operatively treated fractures, or displaced fractures that are inadequately reduced (Rammelt et al. 2006). Clinically, a midfoot malunion will present with functional disability and pain over the subtalar and transverse tarsal joints, which occurs more often in cases of deep venous thrombosis (Daniels et al. 1996; Sangeorzan et al. 1992; Sproule et al. 2012).

Nonunion of the talar neck is being observed in up to 12% of patients (mostly after Hawkins type III fractures), mainly due to inadequate reduction or fixation (Lindvall et al. 2004;

Lorentzen et al. 1977). AVN of the talus can present as a specific complication after talar neck fractures. Talar AVN results from an interruption of the blood supply from the sinus tarsi and tarsal tunnel (tibial anterior and tibial posterior artery anastomosis). Most studies indicate a correlation with the initial degree of concomitant fracture dislocation (Elgafy et al. 2000; Mindell et al. 1963; Santavirta et al. 1984).

Avascular necrosis occurs in 0–24% of cases after Hawkins type I, 0–50% after Hawkins type II, and 33–100% after Hawkins type III and IV fractures (Adelaar and Madrian 2004; Metzger et al. 1999). In open fractures the risk for AVN is genuinely increased (Elgafy et al. 2000; Lindvall et al. 2004; Mindell et al. 1963). A relative increase in the density of the talar body on plain radiographs can suggest the presence of osteonecrosis. Approximately half of the patients with this early finding will undergo revascularization of the talar body without structural collapse (Babu and Schuberth 2013; Elgafy et al. 2000; Gerken et al. 2011). This revascularization process can take up to 2 years after injury.

The appearance of a radiolucent zone 4–8 weeks after the injury at the subcortical bone of the talar dome indicates bone remodeling (Hawkins sign, Fig. 42.8) and is highly predictive for talar body revitalization.

The extension of this necrosis can be visualized best on MRI, but should not be performed before 3 weeks post-injury because of the posttraumatic classical bone marrow edema (Thordarson et al. 1996). Complete AVN of the talus may lead to total collapse of the talar dome, and this can require additional procedures like necrectomy, bone grafting, and tibiotalar or subtalar fusion (Adelaar and Madrian 2004; Rammelt et al. 2006). Preservation of the talonavicular joint is important to allow for remaining midfoot stability and support (Zwipp et al. 1998).

Fig. 42.8 Sagittal T1 MRI view of a talar body stress fracture with Hawkins sign. Photo Copyright: Dr. Pieter D'Hooghe (Chapter corresponding author)

Talar body fractures are more likely to evolve to posttraumatic arthritis than talar neck fractures (Ebraheim et al. 2008; Pearse et al. 1992; Sneppen et al. 1977), and despite seemingly effective treatment, more than half of patients will develop arthrosis in the ankle or subtalar joint eventually (Lindvall et al. 2004; Sanders et al. 2004; Vallier et al. 2014). The reported rates of posttraumatic arthritis after talar neck and body fractures vary considerably from 16 to 100% which may be due to the lack of uniform criteria and differences in follow-up (Lindvall et al. 2004; Schulze et al. 2002).

Although the arthritis risk increases over time, not all cases of posttraumatic arthritis become symptomatic. Malalignment of the talar neck produces significant load alterations in the ankle and subtalar joints and leads to inferior clinical results. Therefore, this condition should be considered as a primary risk factor toward posttraumatic arthritis (Daniels et al. 1996; Lindvall et al. 2004). Consequently, secondary procedures such as tibiotalar or subtalar arthrodesis may be indicated. They can be effective in relieving pain and improving overall satisfaction rate. To date no reliable arthroplasty option exists for the subtalar and talonavicular joints. Ideally, with careful attention to surgical timing and technique, complications can be limited to those associated with the characteristics of the initial injury such as direct damage to the soft tissues, blood supply, articular cartilage, and bone.

42.15 Functional Outcome

The clinical outcome after talar neck fractures depends on injury severity and treatment success. Predominant negative prognostic factors are the initial degree of dislocation, articular cartilage damage, bony comminution, and soft tissue disruption and necrosis. Adequate anatomical and stable talar neck fracture treatment is of the highest importance when working toward a reasonable functional and cosmetic outcome (Coltart 1952; Lindvall et al. 2004).

42.16 Conclusion

Fractures of the talar neck are rare but serious injuries. They are frequently seen in high-energy and polytraumatized patients and can evolve to debilitating complications and functional limitations. The vast majority of talar fractures are intra-articular fractures.

When adjacent soft tissue injury permits, urgent reduction of associated dislocation is mandatory, together with open reduction and internal fixation (ORIF) for displaced fractures. Restoration of articular and axial alignment in the surgical treatment setup is necessary to optimize ankle function.

The most common long-term complication after talar neck fracture is posttraumatic arthritis (PTA). The rate of PTA appears to increase over time.

Ideally—and with careful attention to surgical timing and technique—complications can be limited to the characteristics of the initial injury, including direct soft tissue damage, blood supply insufficiency, and articular cartilage and bony damage.

An arthroscopic-assisted ORIF technique can offer advantages in the treatment of talar neck fractures, such as improved ankle and subtalar joint anatomical congruency restoration.

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Part VII

Miscellaneous

43

Simulation Training and Assessment in Fracture Treatment

Coşku Turhan, Gürhan Dönmez, Gazi Huri,
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43.1 Introduction

Virtual reality (VR) typically refers to computer technologies that use software to generate the realistic images, sounds, and other sensations replicating a real environment (or create an imaginary setting) and simulate a user's physical presence in this environment (Chao et al. 1997). Virtual reality has been defined as a realistic and immersive simulation of a three-dimensional environment, created using interactive software and experienced or controlled by movement of the body or as an immersive, interactive experience generated by a computer (McColl et al. 2006). Virtual reality headsets are used by different industries like education and training, video games, entertainment, fine arts, engineering, heritage and archaeology, architectural design, urban design, therapy, theme parks, concerts, retail, charity, exercise and fitness, film, media, marketing, and sports.

Medical VR is an area with fascinating possibilities. It has not just moved the imagination of science fiction fans, but also clinical researchers and medical practitioners. Although the field is new, there are already great examples of VR having a positive effect on patient's lives and physicians' work (Xia et al. 2000). Medical VR can be used in many fields including psychology, medicine, neuroscience, physical therapy, occupational therapy, mental health therapy, motor and cognitive skills rehabilitation, and clinical skills training. Some areas in which VR is currently being developed at a fast rate include exposure therapy, post-traumatic stress disorder, pain management, phantom limb pain control, and social cognition training for young adults with autism and meditation (Ortiz-Catalan et al. 2014).

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43.2 The Evolution of Virtual and Augmented Reality for Educating Surgeons

The recent surge of VR technologies has brought with it several advancements in many sectors. One industry that has made significant strides with the introduction of VR and augmented reality (AR) is education. The immersive nature of VR along with its inherent interactivity makes it particularly easy to engage the subject with the material being learned. Imagine teaching a young boy or girl about how a car engine works using static diagrams and verbal explanations compared with the same child being able to pull apart each engine component in 3D with an adjacent virtual tutor providing a real-time explanation of each part. The perceived effectiveness of the second option is why VR has developed into a multi-billion dollar industry just a few years since its inception.

The availability and cost-effectiveness of VR and AR hardware and software are essentially what drives the industry. The more people who use it for various applications increase investments and the number of sectors that develop applications for it. An interesting fact related to VR and AR is the investments in these technologies that are largely based on perceived application potential (Ponce et al. 2014). Today, there is a multitude of delivery platforms with a user base, that is, already has basic knowledge in system functions. The accessibility of the hardware along with an already formed user base made it easy for educational platforms to be developed, hence its growing use in the medical and surgical training arena. After the platforms were established, the addition of low cost or free software enabled more people to get comfortable wearing headsets and using controllers. This created enormous opportunities for developers to further share ideas, game engines such as Unity (Unity Technologies, San Francisco, CA, USA), Unreal (Epic Games, Cary, NC, USA), and other VR experiences. This has opened the door for medical and surgical training simulations. What's really the key for medical and surgical training is the hands-on approach and the ability to use tools and machines to simulate real-life scenarios (Fig. 43.1). What makes VR also appealing for medical and surgical education is to be able to strip apart layers of the human body and enlarge microscopic detail as needed while still staying fully engaged in the procedure. In other words in VR, one can create incisions, can perform real-life surgery, but also can zoom in to observe individual blood vessels to see how the blood is circulating. So the infinite scaling, in addition to being able to use actual medical or surgical tools, is an immense advantage to learning in VR. Worldwide, practitioners have already started using VR in universities to teach medical students. Studies show that more than 50% of surveyed practitioners find VR 'very useful' and 30% find it is of 'some use'. Only 5% find VR to have no use (Al-Khalifah et al. 2006). The same study has also suggested that more than 40% of all practitioners think VR can be used 'now' to train students instead of sometime 'in the future'.

One of the largest hurdles in medical education is finding a sufficient cadaver supply for teaching medical and surgical anatomy. Cadavers are expensive and difficult to locate, to store, and to maintain tissue quality. However, they are unequivocal when it comes to providing the necessary training for real-life scenarios. With VR the need for cadavers is minimized. Many people complain about the lack of 'touch' when it comes to simulations, which is a valid concern. Feeling how deep the skin goes, what a ligament feels like compared with a nerve, artery, or vein, etc. These are essential skills that medical physicians and surgeons must possess. In daily practice, use of robotic assistance is a growing trend to improve surgical procedure precision, safety, and patient outcomes. Technological improvements make it easier than ever for VR to be used as a tool to train surgeons since the difference between the actual use of these tools and VR applications is less as the technology evolves. Moreover, many VR innovations are emerging that improve haptic feedback such as forces, vibrations, and motions,

Fig. 43.1 A virtual reality experience requires special glasses and handles (VirtaMed Lab./Zurich)

where the user feels the pressure of the medium they observe in the VR headset as they press their controller against it (Gobbetti and Scateni 1998). Within this scenario, in the very near future, a medical student will be able to easily distinguish between different tissues. This will serve to further decrease the size of the gap between reality and virtual reality. Medical education will most probably change dramatically in the near future, trending substantially towards VR and AR. The sceptics and traditionalists will argue that nothing will replace a real human for training, but advances in VR and AR technologies will be found to be readily available, cost-effective tools that will enhance medical and surgical training.

43.3 Surgical Training

Virtual reality technologies have the potential to support medical education and training (Riener and Burgkart 2001). Training for surgeons usually involves cadaveric specimens and a gradual process of assisting more experienced physicians before becoming responsible for more significant tasks at the most critical moments during a surgical procedure. Virtual reality could provide another means of practice, without any risk to real patients through 3D surgery simulators with haptic feedback. For the first time in the history of medicine, on 14 April 2016, Dr. Shafi Ahmed, a cancer surgeon, performed an operation using a

VR camera at the Royal London Hospital. Everyone could participate in the operation in real time through a website (Medical Realities, London, UK). Integration of VR into the orthopaedic curriculum has the potential to save time in the operating room, reduce operative errors, and improve the surgeon's overall educational experience. In the future the public will expect their surgeons to train using simulators.

Surgical simulation has become increasingly relevant to orthopaedic surgery education and could translate to improved operating room proficiency in orthopaedic surgery trainees (Mabrey et al. 2010). Simulation training provides the opportunity to develop surgical skills in a controlled environment while minimizing patient risk, operating theatre time, and financial expenditure. Simulators allow orthopaedic surgeons to use various surgical instruments to operate on virtual anatomic structures, such as bones, prostheses, and bone grafts, to simulate every procedure on the rigid structures for complex orthopaedic surgeries, including arthroplasty, corrective osteotomy, open reduction of fractures, and amputation (Hsieh et al. 2002; Tsai et al. 2001). Virtual reality training has been shown to improve orthopaedic surgical technical skills (Aïm et al. 2016; Rebolledo et al. 2015).

Diagnostic knee arthroscopy is a common procedure that orthopaedic residents are expected to learn early in their training (Mabrey et al. 2002; Madan and Pai 2014). Arthroscopy requires a different skill set from traditional open surgery, and many orthopaedic residents feel less prepared for arthroscopic procedures (Jacobsen et al. 2015). The simulators used for arthroscopy training can be broadly classified into physical simulators such as cadavers, animals, models and box trainers, virtual reality simulators, and hybrid simulators that combine virtual reality simulation with physical components that allow tactile feedback. Virtual reality simulation training and testing provide an opportunity to ensure basic medical and surgical skills competency before proceeding to supervised procedures in patients (Cannon et al. 2014; Jacobsen et al. 2015). Three high-fidelity arthroscopic VR simulators, each with multiple instructional modules and simulated arthroscopic procedures, were assessed for face validity, and the results demonstrated that each simulator had satisfactory intra-articular quality, while ArthroS has the highest overall face validity (Martin et al. 2016). The ArthroS simulator (VirtaMed AG, Zurich, Switzerland) had good task construct validity based on established objective outputs. However, the passive haptic feedback of the simulator needs improvement (Roberts et al. 2017).

Fracture fixation is the most common procedure in orthopaedic surgery, and residents may benefit from simulated fracture fixation (LeBlanc et al. 2013). The performance of residents on a virtual simulator that allows them to practice the surgical fixation of fractures by providing a sense of touch (haptics) has not yet been compared with their performance using other methods of practicing fracture fixation. Simulation training has also been used for the treatment of intra-articular fractures (Akhtar et al. 2015; Blyth et al. 2007). Blyth et al. (2007) developed a personal computer-based virtual reality training system for hip fracture fixation that comprises a surgical simulator and an assessment component. The simulator allows hip fracture fixation to be performed on a virtual hip model using two-dimensional radiographic images to guide fracture reduction and implant placement. They reported that the simulator had good face validity, with the majority of subjects stating it provided a realistic view of the operating environment and that the three-dimensional view that was provided by the system was adequate (Blyth et al. 2007).

Also, Robotic Orthopaedic Surgery is a recent issue. This surgery is using four important components. They are image-guided, navigation, robot, and haptic technology which all of them are virtual technologies which were adapted to manual environment (Figs. 43.2 and 43.3). Education-assisted simulation robotic surgery can be adapted to VR easily for education of the young surgeons.

Fig. 43.2 Surgery controlled by the surgeon in the monitor

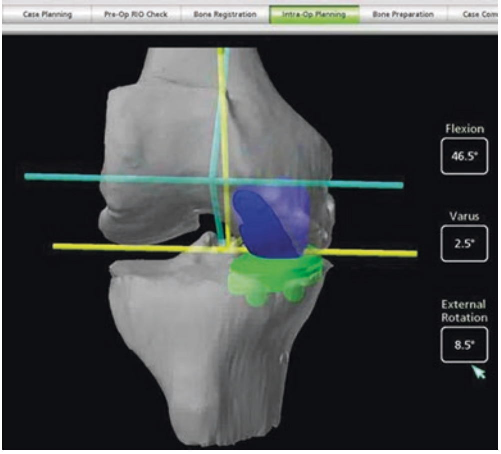

Fig. 43.3 Cutting edges more precisely assisted by haptic technique

43.4 Conclusion

Virtual reality training is a new and interesting way for the beginners to achieve basic navigation skills necessary to perform arthroscopic surgery. Further studies in terms of the transferability of the skills acquired on the VR unit to the operating theatre are needed. Virtual reality and AR are most probably the future of orthopaedic trainee education. Their applications may be particularly beneficial for the training of surgeons who perform arthroscopic-assisted fracture fixation.

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44

Return to Play After Intra-articular Knee Fractures

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44.1 Introduction

The knee consists of three articulations: lateral tibiofemoral, medial tibiofemoral, and patellofemoral (Standring 2005). As a weight-bearing joint, the knee is prone to injury both during daily activities and in sports. Injuries to the knee are especially prevalent in contact sports, such as soccer, basketball, volleyball, hockey, and American football. According to National Collegiate Athletic Association (NCAA) statistics from 1988–1989 to 2003–2004, more than 50% of all injuries involved the lower extremity (Hootman et al. 2007). In an epidemiological study of elite male football players from 2001 to 2013, 45% of traumatic fractures and 86% of stress fractures affected the lower extremity (Larsson et al. 2016). In a Union of European Football Associations (UEFA) study, the incidence of knee injuries among professional football players between 2001 and 2008 was reported to be 18% (Ekstrand et al. 2011). The knee was also the most frequent site of lower body injury (33%) during the IIHF Ice Hockey World Junior Championships between 2006 and 2015 (Tuominen et al. 2017).

Physicians must remember that athletes represent a subset of patients that differ from the general population. The motivations and expectations of this patient group may necessitate the use of a progressive rehabilitation program that enables the injured athlete to return to play as soon as safely feasible. Despite successful rehabilitation and generally positive patient outcomes following intra-articular knee fractures, some studies suggest that traumatic knee injuries increase the risk of post-traumatic osteoarthritis (Lotz 2010; Stiebel et al. 2014). The lifetime risk for developing osteoarthritis in patients with previous knee trauma has been reported to be almost 60% (Murphy et al. 2008). Small differences in intra-articular knee fracture type may be associated with different rehabilitation program timeframes; therefore, the timing of safe return to sports varies. This chapter discusses these considerations that are related to intra-articular fractures of the knee.

44.2 Distal Femur Fractures

Distal femur fractures are relatively uncommon in comparison with fractures to other parts of the femur (Martinet et al. 2000; Obakponovwe

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et al. 2012). The postoperative physiotherapy protocol depends on multiple factors including (but not limited to) fracture pattern and osteochondral quality and whether the fracture was treated conservatively or surgically. If the fracture was treated surgically, considerations including the type of implants, plates, or screws that were used to achieve fixation and the stability of that fixation must be considered when the physician considers when to begin and how quickly to advance the rehabilitation program (Ronga et al. 2016). Physiotherapy should, however, be initiated early to help prevent stiffness, increase pain-free knee range of motion, and prevent functional limitations. Some surgeons recommend the use of postoperative braces to prevent knee valgus and varus stress and non-weight-bearing restrictions for 12 weeks or more after surgery or until fracture healing can be confirmed radiographically (Gwathmey Jr et al. 2010; Ronga et al. 2016). Fracture to either the medial or lateral femoral condyle often has an intra-articular component, as does a supra- or intercondylar Hoffa's fracture (White et al. 2015). Depending on the fixation method, the postoperative care regimen varies. In a case series following unicondylar (Lewis et al. 1989; Vaishya et al. 2009) and bicondylar (Bali et al. 2011; Papadopoulos et al. 2004) Hoffa fractures, 2 weeks of extension cylinder cast immobilization have been recommended. Others have recommended unrestricted active and passive knee range of motion exercises early after unicondylar fracture surgery (Ercin et al. 2017; Holmes et al. 2004; Miyamoto et al. 2006) but with the avoidance of weight-bearing. Other reports have recommended weight-bearing restrictions for 6 weeks following surgery for intra-articular unicondylar Hoffa fractures (Vaishya et al. 2009) or bicondylar fractures (Bali et al. 2011; Calmet et al. 2004; Zeebregts et al. 2000). As progressive weight-bearing is re-established, the postoperative regimen can shift toward restoration of full muscle strength and a gradual return to full activities of daily living and sports without experiencing any knee pain or other complains at the injury site.

44.2.1 Tibial Eminentia Fracture

Tibial eminentia fractures were first described by Poncet (1875) as an injury to the spine of the tibia including the anterior cruciate ligament (ACL). This fracture usually occurs in pediatric patients between 8 and 14 years of age and much less in adult patients (Accousti and Willis 2003; Hanley and Amendola 2016; Toye et al. 2002). Rehabilitation program progressions may be complicated due to injuries at adjacent knee joint tissue. In general, type I and type II fractures that are minimally displaced are treated with closed reduction. Following closed reduction, radiographs should be obtained every 1–2 weeks to insure that there is no displacement. Type I eminentia fractures are usually treated nonsurgically, using long-leg cast immobilization for 4–6 weeks (Ahmad et al. 2016; Kendall et al. 1992; Liljeros et al. 2009; Molander et al. 1981; Tudisco et al. 2010). There is no consensus about the position the knee should be placed in to achieve the best possible outcome during cast immobilization. Some researchers have advised immobilization with the knee in full extension (Ahmad et al. 2001; Molander et al. 1981). One report warned that knee immobilization in full extension or hyperextension may increase the risk of a compartment syndrome due to excessive popliteal artery tension (Anderson and Anderson 2011). Others have advised immobilizing the knee between 10° and 20° of flexion (Beaty and Kumar 1994; Meyers and McKeever 1959).

If nonsurgical closed reduction treatment fails or if fracture instability is noted, surgery is indicated. The postsurgical rehabilitation program may vary depending upon whether an arthroscopic or open surgical approach is selected, with considerations for associated injuries identified during surgery, or related to postsurgical complications (Doral et al. 2001). Early rehabilitation generally makes use of a removable long-leg brace that is initially locked in full extension to enable progressive protected knee joint range of motion. Therapeutic exercises performed at this time include straight leg raises with a primary focus on strengthening the quadriceps femoris at the knee and the hip

Fig. 44.1 (**a**) Proprioceptive exercises. (**b**) Proprioceptive exercises can be combined with sports specific activities on the playing field

extensors, flexors, adductors, and abductors. Although partial weight-bearing within pain-free limits is allowed, full weight-bearing is restricted over the initial six postsurgical weeks to ensure effective fracture healing with minimal anterior tibial displacement. When full weight-bearing is allowed, proprioceptive exercises with and without perturbations on stable and unstable surfaces should be considered to re-establish lower extremity neuromuscular control (Fig. 44.1a, b). Following successful completion of specific guidelines, return to sports is usually allowed after 4–6 months depending on functional recovery after surgery (Anderson and Anderson 2011).

44.2.2 Patella Fractures

Through direct trauma, indirect trauma, or combination of the two, patella fractures represent approximately 1% of all skeletal fractures (Jarraya et al. 2017). The rehabilitation progression and return-to-play decision-making timeframe vary depending on whether a nonsurgical, open surgical, or arthroscopic treatment approach has been advocated. Nonsurgical treatment is indicated for patellar fractures that display a clinically intact knee extensor mechanism and are non-displaced and closed. These include transverse and vertical patella fractures with less than a 2-mm articular step-off (Melvin and Mehta 2011). Boström (1972) reported good or excellent patient outcomes at a mean 9-year follow-up in 287 patella fractures treated nonsurgically with plaster knee immobilization for a mean duration of 4 weeks (Boström 1972). Melvin and Mehta (2011) recommended early weight-bearing with a hinged brace locked in full extension. Patients were encouraged to start isometric quadriceps femoris setting and straight leg raise exercises as soon as knee pain had subsided. At 1–2 weeks post-surgery, active-assisted knee range of motion exercises was started and resistance training exercises at 6 weeks post-surgery (Melvin and Mehta 2011). In a recent study, Kakazu and Archdeacon (2016) stated that at 2–3 weeks, patients can start passive knee range of motion between 0° and 30°, increasing the arc of motion by 15° per week. Following this progression, at approximately 8 weeks, full passive knee range of motion was restored, and patients were allowed to weight-bear as tolerated without knee immobilization (Kakazu and Archdeacon 2016). The presence of a knee joint hematoma requires aspiration before the knee is immobilized in full extension in a long-leg cast or brace for 3–6 weeks. A gradual return to full weight-bearing closed kinetic chain therapeutic exercises such as stationary cycling, lunges, and mini-squats can be initiated at approximately 6 weeks post-surgery. By 12-weeks post-surgery, full knee range of motion should be re-established (Hall 1998).

Different surgical approaches warrant different postoperative rehabilitation progressions. Early knee motion and full weight-bearing in a hinged knee brace are recommended in patients treated with stable fixation. Early use of continuous passive motion devices may reduce knee joint stiffness and improve articular cartilage healing. Prolonged immobilization is generally discouraged. For fractures with stable internal fixation, Melvin and Mehta (2011) recommended early physiotherapy and weight-bearing as tolerated while limiting knee flexion to 30° for 4 weeks. In the presence of tenuous fracture fixation and partial patellectomy, or in a noncompliant patient, full weight-bearing is only allowed with the knee immobilized in full extension in a long-leg cast for 6 weeks before switching to a hinged knee brace. Isometric quadriceps setting exercises and straight leg raises are encouraged as soon as pain subsides (Melvin and Mehta 2011). Knee immobilization in a plaster cast for longer than 6 weeks is discouraged (Mehling et al. 2006). Early isometric quadriceps exercises are recommended as early as possible following surgery to offset the effects of knee immobilization (Dietz et al. 2009; Tian et al. 2011). Others have recommended the use of a removable knee brace locked in full extension and unlocked for physiotherapy focusing on gradually improving knee flexion (Kakazu and Archdeacon 2016). Physiotherapy focusing on progressive knee motion is started at 2–3 weeks post-surgery. At 6 weeks, if radiographic evidence of healing is present, the patient may proceed to progressive resistance exercises. Brace use can be discontinued at 12 weeks post-surgery when fracture healing is radiographically confirmed. Progressively more intense and sports-specific physiotherapy may be continued for up to 6 months post-surgery culminating in restoration of non-impaired range of motion, muscle strength, and power before allowing the patient to gradually return to sports activity (Kakazu and Archdeacon 2016).

44.2.3 Tibial Plateau Fractures

Tibial plateau fractures are usually associated with high-energy trauma. There are limited data about rehabilitation programs of post-tibial plateau fracture injuries. Zura et al. (2007) suggested that postoperative rehabilitation protocols following tibial plateau fracture surgery should emphasize early knee motion and recommended the use of a continuous passive range of motion device to prevent stiffness. Lower extremity or knee-specific bracing may be performed on an individualized basis. Typically, these patients are kept at non-weight-bearing status on the injured extremity for 10–12 weeks post-surgery starting progressive weight-bearing and activities thereafter (Zura et al. 2007). Nevertheless, some have reported the use of immediate active knee motion from 0° to 90° in a hinged knee brace for patients with Schatzker types I–IV tibial plateau fractures (Bonasia 2016). In this report the knee brace was discontinued after 8 weeks, and partial (or toe touch) weight-bearing was initiated. Full weight-bearing was permitted at 12 weeks post-surgery (Bonasia 2016). In contrast, the management of complex Schatzker types V–VI tibial plateau fractures is more complicated. To avoid loss of terminal knee extension, Siegel and Tornetta (2016) recommended early knee immobilization in full extension as opposed to 30° of flexion. At 2–3 weeks post-surgery, patients are allowed to start progressive knee range of motion exercises in a hinged brace. Patients maintain non-weight-bearing status over the initial 12 weeks of rehabilitation. Following this, and with radiographic confirmation of fracture healing, patients can discontinue brace use and start weight-bearing as tolerated. Lower extremity strength training exercises are also initiated at this time. Patients are restricted to nonimpact activities until normal lower extremity strength has been restored (Siegel and Tornetta 2016).

Several case reports have described tibial plateau fractures in combination with anterior cruciate ligament (ACL) injury (el-Hage et al. 1998; Gobbi et al. 2011; Mithofer et al. 2004). In such cases physiotherapy including continuous passive motion device should start immediately, and progressive, protected weight-bearing should be maintained for the initial 8 weeks following

ACL reconstruction. Full weight-bearing and full knee range of motion are allowed at 5 months post-surgery. Repeat radiographs should be obtained at 12 months post-surgery to confirm fracture healing (Gobbi et al. 2011).

44.3 Tibial Tuberosity Avulsion Fractures

Tibial tuberosity fractures are uncommon, representing approximately 1% of all physical injuries in the adolescent athlete (Boyle and Dawe 2011). They are often associated with patellar tendon avulsion. According to the Watson-Jones classification, there are three types of tibial tubercle fractures. Non-displaced type I fractures can be treated by immobilization in a long-leg cast with the knee in full extension for 4–6 weeks, followed by progressive quadriceps muscle strengthening exercises. Type IB and nearly all type II and type III fractures require surgical treatment; however, according to Mencio et al. (2015), a similar postsurgical progression is followed. When full knee motion has been restored, patients may be allowed to start sports activities at approximately 12 weeks post-surgery (Mirbey et al. 1988). In type II and III tibial avulsion fractures, Ogden et al. (1980) reported that most adolescent patients returned to pre-injury activity levels between 16 and 18 weeks following cast removal (Mosier and Stanitski 2004). In a retrospective study of 19 type I–III tibial avulsion fractures treated with long-leg cast knee immobilization for a mean 4.5 weeks (range from 2 to 6 weeks), Mosier and Stanitski (2004) reported that by 5 months, all patients had full knee motion and had returned to pre-injury activity levels.

44.4 Conclusion

There is no agreed upon return-to-play time guideline consensus for advancing patients following intra-articular knee fracture treatment. Individual patient demographics such as age, sex, tissue regenerative capabilities, personal medical and injury histories, smoking, as well as psychological factors each have the potential to influence the patient's prognosis for returning successfully to more intense activities of daily living and sports. In addition to providing direct visualization of knee joint surface integrity, arthroscopy in association with intra-articular fracture management may provide a comprehensive depiction of the true osteochondral and capsuloligamentous tissue injuries. Serial radiographic imaging is important to follow and confirm fracture healing status prior to initiating rehabilitation and sports-specific training impact loading. Before returning to sports, performance-based muscle strength, neuromuscular control, and confidence in the injured limb should be obtained (Fig. 44.2). Functional testing includes single-leg jumping tasks. Other functional tests of importance include assessments of patient, balance, proprioception, and dynamic knee stability (Fig. 44.3a, b). Tests such as these are essential to establish a full appraisal of the patient's true readiness to safely return to sports participation (Clover and Wall 2010; Creighton et al. 2010).

Fig. 44.2 Isokinetic strength tests should be performed to compare injured/non-injured side knee extensor/flexor torque ratios

Fig. 44.3 (**a**, **b**) A sport-specific field-testing program should include agility, balance, and endurance tasks that are related to skills of a specific

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