E. Carlos Rodríguez-Merchán
Juan Carlos Rubio-Suárez
Editors

Complex Fractures of the Limbs

Diagnosis and Management

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Preface

Bone fractures are becoming more and more common and complex, and therefore their management is becoming more and more difficult. Generally speaking, bone fractures are produced in high-energy traumatisms, mainly in traffic accidents, so that many of them take place in the setting of a polytrauma patient. We consider that a bone fracture is complex when there is marked comminution, there are severe soft tissue injuries associated with it, it takes place in an osteoporotic bone, or it is associated with a previous implant (for bone fixation or total joint replacement). If a complex fracture is not treated in the appropriate way, it may cause severe complications and sequelae (nonunion, malunion, infection). In this book we have analyzed the current management of complex fractures of the limbs based on the experience of the contributing authors and on an in-depth review of the literature.

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1 Complex Fractures of the Proximal Humerus

Elena Casado-Sanz, Raúl Barco, and Samuel A. Antuña

1.1 Introduction

Proximal humerus fractures are very common. In patients over 65, they are second only to distal radius fractures as the most common fractures of the upper limb. If we analyze their overall frequency, proximal humerus fractures are the third most common fractures behind proximal femur and distal radius.

Seventy-five percent of the cases occur in patients above age 60 that have suffered direct trauma after an accidental fall from their own height. In younger patients, however, high-energy trauma to the shoulder is the usual mechanism of injury [1].

Radiographic diagnosis of these fractures should always be performed with appropriate projections. The fracture usually can be framed within a classification with the help of an anteroposterior and lateral shoulder view in the plane of the scapula. With a CT scan, it would be easier to evaluate complex fractures such as fracture dislocations, fractures associated with the glenoid and articular humeral head, posterior displacement of the greater tuberosity, and the presence of an associated fracture of the lesser tuberosity.

Although there are many classifications for cataloging these fractures, none of them is complete and useful enough to frame all fracture patterns and their possible variations. We will use the Neer Classification in this chapter, as it is one of the most widespread. It is based on the four-part anatomy of the proximal humerus and defines the displacement as an angulation greater than 45° or a separation between fragments of greater than 1 cm. This leaves us with 1-part (non-displaced), 2-part, 3-part, and 4-part fractures. The Neer Classification also assesses the viability of the humeral head according to the fracture pattern and the soft tissue attachments and the humeral head's relationship to the glenoid to classify fractures associated with dislocation [2].

Approximately 80 % of the cases are considered non-displaced fractures and treated conservatively. Among the remaining 20 % of cases, there is a small percentage of fractures that can be solved with a simple osteosynthesis [2, 3]. Since this chapter aims to review complex fractures of the proximal humerus and their potential treatments, we will exclusively cover these types of fractures.

1.2 Three- and Four-Part Fractures in Young Patients

Treatment of 3- and 4-part fractures in young people is challenging. The first thing to consider in all cases is the risk to the potential disruption

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to vascularization of the humeral head. Major blood supply to the proximal humerus comes from the ascending branch of the anterior humeral circumflex artery. Patients with 4-part fractures, anatomical neck fractures, fracture dislocations, or fracture patterns with altered medial hinge or minimal medial metaphyseal extension may lead to eventual avascular necrosis of the humeral head and, therefore, worse results [4].

In young patients, the treatment goals should aim to achieve an anatomic reduction of the fracture and the joint, with stable fixation, to restore mobility and relieve pain. Over the years, attempts at achieving those aims have included a variety of conservative and internal fixation methods. Of the latter, the most widespread methods used are nails or plates. The use of shoulder arthroplasty in young people is reserved for fractures impossible to synthesize and when there is previous joint pathology.

In 2001, based on a review of all published literature regarding 3- and 4-part fracture treatments, Misra et al. concluded that conservative treatment does not provide good results for these patients in relieving pain and in post-injury range of motion [5]. Open reduction and internal fixation with plate or nail is, therefore, the treatment of choice.

Fixation with an intramedullary nail is known to be a good option for 2-part fractures, but for 3- and 4-part fractures, there are numerous studies that have reflected a higher complication rate. The worse results in 3- and 4-part fractures were linked to the inherent qualities of nail usage (loosening of screws, penetration of the glenohumeral joint, subacromial pain due to implant protrusion) and also due to the possible malreduction of tuberosities and varus misalignment [6].

However, in other studies, such as Konrad et al., which compared 211 three-part fractures treated with intramedullary nail or by plate, they saw no significant differences in the complication rate nor in the outcome in the Constant and Neer questionnaires [7].

This could be due to the different complexity of the fracture. In another study by Adedapo et al., 3- and 4-part fractures treated with intramedullary nail were examined separately. Despite good results, we can observe how results worsened in 4-part fractures as compared to 3-part fractures [8] (Table 1.1).

Furthermore, the fixation with plate offers the advantage of giving a stable fixation but at the expense of increased soft tissue dissection, so it can further compromise head vascularization. This technique gives good results but not without complications (Table 1.2).

Table 1.1 Comparison of results of three- and four-part fractures treated with intramedullary nail

	N	FLX	ABD	ER	IR	Neer	Constant
3 part	10	170	155	60	90	83.6	88.4
4 part	6 (26.1 %)	100	120	30	50	62.5	67
3 and 4 part with shaft FX	7 (30.4 %)	115	90	30	40	69.14	69

Reproduced with permission from Adedapo and Ikpeme [8]

Table 1.2 Results of three- and four-part fractures treated with plate

Author	Soliman et al. [9]	Moonot et al. [10]	Kim et al. [11]
Type of study	Prospective	Prospective	Retrospective
N	39	32	21
Age	29.6	59.9	66
FX	4-part fracture dislocations	3 and 4 part	4 part
Follow-up	18 months	11 months	27.5 months
Union rate	93.3 %	97 %	100 %
Constant/Neer	77 (65–90)	66.5 (30–92)	92 (81–100)
Complications	2 infections 7 NAV (anatomic neck) 1 screw loosening 3 nonunion (anatomic neck)	1 NAV 1 nonunion 1 infection 2 screws loosening	No NAV No nonunion

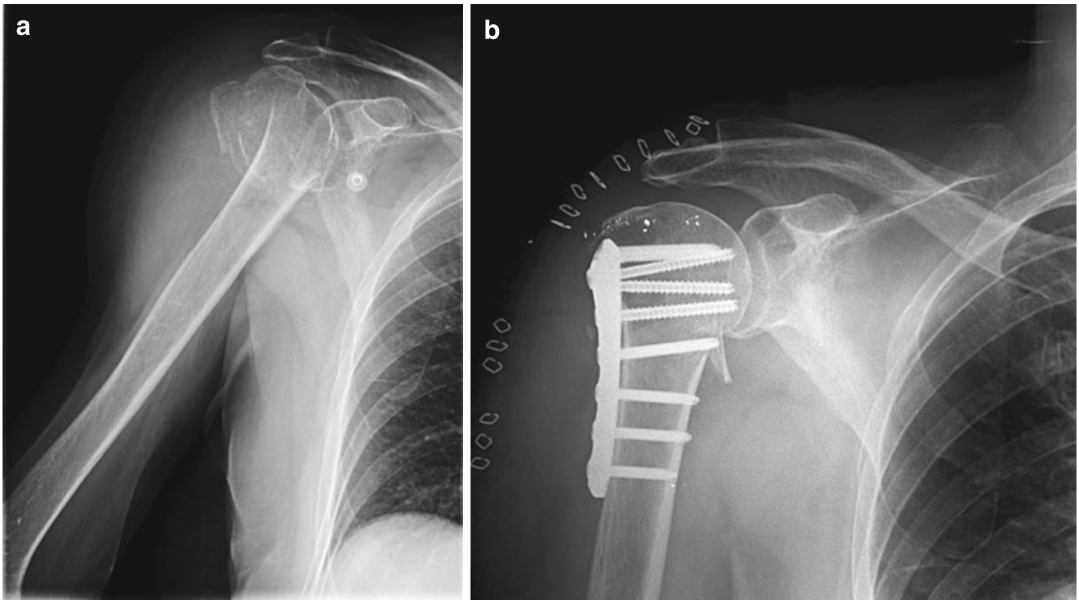

Fig. 1.1 (**a**) Preoperative AP view of a complex proximal humerus fracture in a 60-year-old patient. (**b**) The fracture was reduced through an anterosuperior approach and fixed with a percutaneous plate with good reduction

In conclusion, according to some studies, in 3-part fractures in young people, it is possible to use an intramedullary nail as long as there is both good fixation and positioning of tuberosities. The results of this treatment are more unpredictable than with plates, which give more stable fixation and allow, in most cases, a more anatomical reduction (Fig. 1.1).

1.3 Three- and Four-Part Fractures in the Elderly

Proximal humerus fractures account for 10 % of all fractures in the elderly, and as the global population continues to age, the incidence of proximal humerus fractures could triple in the next 20 years. Fractures are complicated in elderly patient care, as they not only increase patient morbidity but also are associated with increased mortality rates.

They have particular characteristics that make treatment options different from those of younger patients. Firstly, these are usually patients with lower functional demand, so they can have good results with conservative treatment. Secondly, comorbidities are present to increase the risk perioperatively. And thirdly, the high degree of osteoporosis in these patients compromises the stability of the fracture fixation by conventional modes [12]. Among the treatment options are conservative treatment, locking plates, shoulder hemiarthroplasty, and shoulder reverse prosthesis.

Fjalestad et al. conducted a randomized study of 50 patients over 60 years old that compared fractures in 3 and 4 parts treated with locking plates versus conservative treatment. It was noted that although the results were less satisfactory radiographically and the avascular necrosis rate was higher in patients treated conservatively, there was no clinical evidence of better clinical outcomes in the fixation group. Meanwhile, the rate of collapse of the humeral head, and the rate of penetration of the screws in the joint because of poor bone quality, made the complication rate higher in the surgical group [13].

For all these reasons, shoulder arthroplasty is reserved as an appropriate treatment for these patients. Shoulder hemiarthroplasty provides advantages compared to conservative treatment in relieving pain and, thus, in improving quality

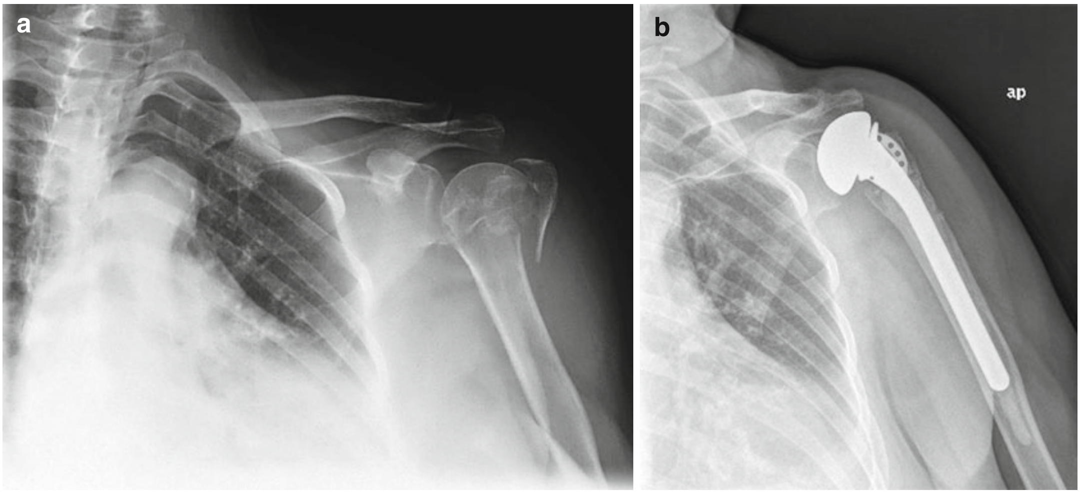

Fig. 1.2 (**a**) Preoperative radiograph of a 72-year-old patient with a complex proximal humerus fracture. (**b**) The fracture was treated with hemiarthroplasty, and the x-ray 2 years after the operation showed resorption of the greater tuberosity and superior migration of the humeral head. This patient had no pain but very limited function

of life. Different studies have shown that there are differences in mobility due to the nonunion or postoperative migration of the tuberosities. Also, the necessity of the tuberosities' union delays and complicates postoperative rehabilitation [14] (Fig. 1.2).

Therefore, in recent years the use of reverse prosthesis for the treatment of acute complex fractures in elderly patients has been introduced. With that change in configuration, the prosthesis has the advantage of improving mobility without it being necessary to have the union of tuberosity with a good position and a healthy rotator cuff, because the deltoid muscle performs the movement for the most part (Fig. 1.3).

Various studies indicate that reversed shoulder prosthesis could have better results than shoulder hemiarthroplasty (Table 1.3).

In conclusion, reverse prosthesis implantation in patients older than 70 years old can be a breakthrough and get reliable and predictable results in terms of improved mobility, rapid recovery, and rehabilitation [14, 15].

Among fractures in the elderly, it is key to also discuss valgus impacted fractures. This type of fracture rarely occurs in young patients. First described by Jakob et al. [16], the fracture pattern has demonstrated reduced risk of development of avascular necrosis due to the maintenance of the periosteum in the medial hinge (21.1–74 % versus 8–26 %) [17].

Treatments for valgus impacted fractures range from conservative treatment to different types of osteosynthesis to shoulder arthroplasty. In several studies, conservative treatment has been shown to have an 80.6 % success rate at 1 year, with average values in the Constant score of 71.8 and 87.1 on the Neer scale. According to the authors, the strength in both flexion and abduction reached 75 % of normal, though patients did not perceive the reduction in mobility subjectively. Even so, these values are inversely correlated with the degree of displacement of the fracture [18].

Therefore, surgical treatment has gained support for achieving anatomical position and restoring better stabilization of the humeral head, which avoids joint incongruity and the malunion of tuberosities thereby preventing posttraumatic arthritis and subacromial syndrome. Still, surgery is not without complications, such as avascular necrosis, stiffness, nonunion, malunion, and persistent pain [19] (Table 1.4).

In summary, in impacted valgus fractures in the elderly, because the risk for avascular necrosis is decreased, conducting osteosynthesis can give good results, though this depends on the specifics of each case and the patient's bone density [19].

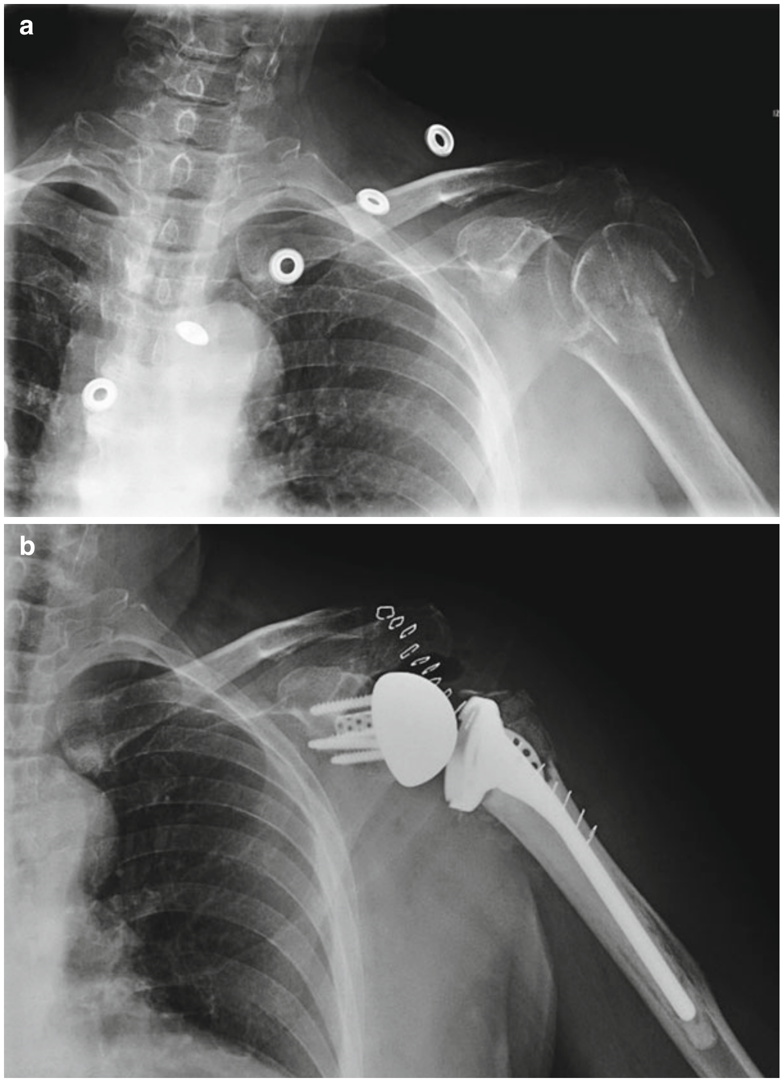

Fig. 1.3 (**a**) AP view of a four-part fracture in an 82-year-old patient with osteopenic bone. (**b**) Patient was treated with a reverse shoulder arthroplasty through a deltopectoral approach

Table 1.3 Comparison of results of proximal humerus fractures treated with hemiarthroplasty and reversed prosthesis

	Gallinet et al. [14]		Garrigues et al. [15]	
	Hemi	Reversed	Hemi	Reversed
N	21	19	12	11
Age	74	74	69	81
Follow-up	2 years	2 years	3.6 years	3.6 years
FLX	53.5°	97.5°	90°	122°
ABD	60°	91°		
IR	54°	31°		
ER	13.5°	9°	31°	33°
Constant	39	53		
ASES			47.4	81.1
EQ5D			64.2	86.6
Complications	3 malunion tuberosities	↓ ER 12 notching	2 malunion tuberosities	1 notching

Table 1.4 Surgical treatment options for valgus impacted fractures of the proximal humerus

	Percutaneous reductions	Locking plates	Arthroplasty
Advantage	No soft tissues disruption	Anatomic reduction More stability Less loosening	No osteonecrosis
Complications	Loosening Migration Infection Less stability	Soft tissue disruption (risk osteonecrosis) False sense of security	Loosening Infection Instability Fracture
Indications	Good bone density No displacement Less than 1 week post-injury No comminution	Displacement Acceptable bone density	Elderly Articular displacement Poor bone quality

1.4 Posterior Fracture Dislocations

Posterior fracture dislocations are uncommon injuries that normally occur during seizures, electrocution, electroconvulsive therapy, and high-energy trauma. They account for less than 3 % of all shoulder dislocations, although their number is increasing in recent years due to the high prevalence of diabetes and drug use among the population. As a result, a greater proportion of dislocations occur during seizures related to hypoglycemia and drug withdrawal. A majority of posterior fracture dislocations occur in males between 35 and 55 years old. Up to 15 % of the cases are bilateral and up to 50 % go unnoticed on the first consultation post-injury.

The shoulder is protected from posterior dislocation by the posterior part of the glenoid and by the static stabilizers, which are the posterior capsulolabral complex and the posterior band of the inferior glenohumeral ligament. Posterior dislocation fractures occur with the arm in a position of internal rotation, 90° of flexion and adduction, or due to sudden contraction of the internal rotators during a seizure.

We can classify them according to three groups: lesser tuberosity fractures, 2-part fractures of the anatomic neck, and complex 3- and 4-part fractures. Concomitant tears of the rotator cuff and neurovascular injury are uncommon, but those diagnoses should be excluded.

Treatment can be divided into three groups according to the degree of joint involvement of the humeral head [20]:

1.4.1 Dislocations with Involvement of Less than 40–50 % of the Humeral Head Surface and No Deformity or Degenerative Changes

This group is usually made up of cases diagnosed immediately or within the first 6 weeks post-injury. The most appropriate treatment is the reduction and subsequent verification of stabilization. If the shoulder is stable throughout a functional range of rotation (usually patients with a humeral head defect occupying less than 25 % of the articular surface), it is immobilized for 4 weeks in neutral or external rotation.

Despite negative reports in recent years, in case of instability, one treatment choice is immobilization in a more stable position. Other options would be the transfer of the subscapularis muscle to the defect (McLaughlin procedure) or, in case of major defect, the transfer of the subscapularis muscle in continuity with the osteotomized lesser tuberosity (Neer modification). Another option for small defects would be disimpaction, elevation, and filling of the depressed osteochondral area of the humeral head with autologous bone graft. In cases of major defect (40–50 % of the humeral head), solutions that provide more stability are recommended, such as structural allografts.

1.4.2 Dislocations with Involvement of More than 40–50 % of the Humeral Head Surface or with Deformity or Secondary Osteoarthritis of the Humeral Head

These dislocations usually occur in patients in whom the diagnosis is delayed or in elderly patients with osteoporotic bone. Open reduction and stabilization with allograft has been the method used for young patients with a defect greater than 50 % and with preservation of the sphericity of the head. However, in elderly patients, or in cases of higher defect or deformity of the humeral head, prosthetic replacement is a better option.

1.4.3 Fracture Dislocations

In cases of fracture of the lesser tuberosity, the treatment is the same as in simple dislocations – fixing either the tuberosity anatomically or into the base of the humeral head defect, if the shoulder is unstable.

The treatment of 2-, 3-, and 4-part fractures, with involvement of the anatomic neck, will depend on the age, patient's condition, and the degree of vascularization and fragmentation of the humeral head and the tuberosities. As with other types of fractures, in young people with good bone density, the treatment of choice is open reduction and internal fixation. Closed reduction with percutaneous fixation would not be considered as it can cause iatrogenic displacement of the fracture. In older people with poor bone quality, the treatment of choice is the replacement of the shoulder.

In 2007, Robinson et al. [21] reviewed 26 patients with acute posterior fracture dislocations treated with allograft in the bone defect area and fixation with plate or screws depending on the type of fracture. In 11 patients the injury was secondary to a seizure (mean age 51 years), and in 15 patients the injury was due to trauma (with a mean age of 57 years). During surgery the capsulolabral complex was not repaired because no damage was found. Discovering the capsulolabral complex intact supports usage of fixation for these young patients because it is possible to maintain head vascularity.

With a 2-year follow-up, they found a 100 % union rate, 83.5 points (75.7–88.5) in the Constant score, 17.5 (12–19) in the DASH score, 175° (60–180°) of flexion, and 169° (45–180°) of abduction. They observed only one case of osteonecrosis, two cases of early posttraumatic osteoarthritis, one case of redislocation due to the collapse of the elevated segment of the humeral head, and two cases of displacement of the greater tuberosity. In all cases, internal rotation was the most restricted movement. There were no signs of posterior instability.

With reduction and early fixation in fractures that had been traditionally treated with shoulder replacement, there have been good results specifically in young patients and acute injuries [21].

Conclusions

Complex fractures of the proximal humerus are challenging. Every attempt should be made to fix fractures in the young patient. Healing of tuberosities is of paramount importance. Nailing has recently gained more popularity in order to reduce the risk of osteonecrosis.

Conminuted fractures in the elderly are very prevalent and their incidence will increase in the future. Hemiarthroplasty yields to poor functional results due to tuberosity nonunion and resorbtion. Either conservative treatment or reverse shoulder arthroplasty are more commonly used nowadays. Future studies should clarify which is the best option for this difficult problem.

References

1. Lind T, Kroner K, Jensen J (1989) The epidemiology of fractures of the proximal humerus. Arch Orthop Trauma Surg 108:285–287
2. Neer CS II (1970) Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg Am 52:1077–1089
3. Naranja RJ, Lannotti JP (2000) Displaced three and four part proximal humerus fractures: evaluation and management. J Am Acad Orthop Surg 8(6):373–382
4. Hertel R, Hempfing A, Stiehler M, Leunig M (2004) Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elbow Surg 13(4):427–433
5. Misra A, Kapur R, Maffulli N (2001) Complex proximal humeral fractures in adults – a systematic review of management. Injury 32(5):363–372
6. Van den Broek CM, van den Besselaar M, Coenen JM et al (2007) Displaced proximal humeral fractures: intramedullary nailing versus conservative treatment. Arch Orthop Trauma Surg 127:459–463
7. Konrad G, Audigé L, Lambert S, Hertel R, Südkamp NP (2012) Similar outcomes for nail versus plate fixation of three-part proximal humeral fractures. Clin Orthop Relat Res 470:602–609
8. Adedapo AO, Ikpeme JO (2001) The results of internal fixation of three-part and four-part proximal humeral fractures with the Polarus nail. Injury 32:115–121
9. Soliman OA, Koptan WMT (2013) Four-part fractures dislocations of the proximal humerus in young adults: results of fixation. Injury 44:442–447
10. Moonot O, Ashwood N, Hamlet M (2007) Early results for treatment of three- and four part fractures of the proximal humerus using the PHILOS plate system. J Bone Joint Surg Br 89-B:1206–1209
11. Kim SH, Lee YH, Chung SW, Shin SH, Jang WY, Gong HS, Baek GH (2012) Outcomes for four-part proximal humerus fractures treated with a locking compression plate and an autologous iliac bone impaction graft. Injury 43:1724–1731
12. Okike K, Lee O, Makanji H, Harris MB, Vrahas MS (2013) Factors associated with the decision for operative versus non-operative treatment of displaced proximal humerus fractures in the elderly. Injury 44:448–455
13. Fjalestad T, O'hole M, Hynas Hovden IA, Blücher J, Stromsoe K (2012) Surgical treatment with angular stable plate for complex displaced proximal humeral fractures in elderly patients: a randomized controlled trial. J Orthop Trauma 26:98–106
14. Gallinet D, Clappaz P, Garbuio P, Tropet Y, Obert L (2009) Three or four parts complex proximal humerus fractures: hemiarthroplasty versus reverse prosthesis: a comparative study of 40 cases. Orthop Traumatol Surg Res 95:48–55
15. Garrigues GE, Johnston PS, Pepe MD, Tucker BS, Ramsey ML, Austin LS (2012) Hemiarthroplasty versus reverse total shoulder arthroplasty for acute proximal humerus fractures in elderly patients. Orthopedics 3:e703–e708
16. Jakob R, Miniaci A, Anson P, Jaberg H, Osterwalder A, Ganz R (1991) Four-part valgus impacted fractures of the proximal humerus. J Bone Joint Surg 73B:295–298
17. Olerud P, Ahrengart L, Ponzer S, Saving J, Tidermark J (2011) Hemiarthroplasty versus nonoperative treatment of displaced 4-part proximal humeral fractures in elderly patients: a randomized controlled trial. J Shoulder Elbow Surg 20:1025–1033
18. Court-Brown CM, Cattermole H, McQueen MM (2002) Impacted valgus fractures (B1.1) of the proximal humerus. The result of non-operative treatment. J Bone Joint Surg (Br) 84-B:504–508
19. DeFranco MJ, Brems JJ, Williams GR, Iannotti JP (2006) Evaluation and management of valgus impacted four part proximal humerus fractures. Clin Orthop Relat Res 442:109–114
20. Robinson CM, Aderinto J (2005) Posterior shoulder dislocations and fracture-dislocations. J Bone Joint Surg Am 87:639–650
21. Robinson CM, Akhtar A, Mitchell M, Beavis C (2007) Complex posterior fracture-dislocation of the shoulder. J Bone Joint Surg Am 89:1454–1466

2 Complex Distal Humerus Fractures

Raúl Barco and Samuel A. Antuña

2.1 Introduction

Distal humerus fractures are, by themselves, complex injuries. However, in this chapter we will be reviewing the more challenging patterns of these fractures. Distal humerus fractures may be challenging due to the presence of severe comminution at the supracondylar level, loss of bone, comminution at the articular surface, or significant soft-tissue compromise. The goal of a stable anatomic reduction and fixation may not always be possible, and variations of the standard surgical technique need to be considered in order to obtain a stable reconstruction and restore a painless functional elbow.

When reconstruction is not feasible, hemiarthroplasty or total elbow arthroplasty may be a last resource to obtain a functional stable elbow. Three groups are generally recognized as they affect specific populations and pose specific challenges including supracondylar fractures, distal humerus articular fractures, and low transcondylar fractures [1].

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2.2 Epidemiology

In the adult population group, these fractures are generally seen after high-energy injuries, usually following motor vehicle accidents, or in the elderly population after falls form a standing height. In the United States, the rate of distal humerus fractures has been estimated in 43 fractures every 100,000 people [2]. Palvanen et al. showed a 395 % increase in these kind of osteoporotic fractures, which he defined as fractures occurring after the age of 60 years and sustained after moderate or minimal trauma [3]. Specifically, the greatest increase (×9) was seen in the group of women above 80 years. This population has seen a greater incidence in articular fractures with comminution of the articular surfaces and columns [4].

Articular fractures are rare. Ring et al. and Dubberley et al. published their surgical experience and reported treating between four and ten of these fractures a year in dedicated upper limb services [5, 6].

2.3 Classification

Supracondylar fractures are generally classified when reporting these injuries using the AO classification, although generally they can be classified in one of three patterns according to the nature of the injury and treatment preference. Type A fractures are considered extra-articular, B fractures are partial articular fractures, and C

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fractures are supraintercondylar fractures. These are further subdivided into three subcategories depending on the degree of comminution of the articular surface [7].

Supracondylar fractures generally involve a fracture line through the supracondylar level and through the articular surface, often presenting with comminution or bone loss at one or both levels. A modification of this pattern of injury may include injury only to one of the columns and is termed partial articular fractures. These injuries generally affect younger patients and can be usually managed with a single plate with or without supplemental screw fixation from the contralateral column through a bilaterotricipital approach.

Articular shear fractures typically affect the capitellum, with or without extension into the trochlea but without involvement of the columns. Using the classification system by Dubberley et al., fractures can be classified as type 1 if they involve the capitellum and a small portion of the lateral aspect of the trochlea with involvement of the posterior part of the humerus. Whenever there is posterior fracture impaction, they are subclassified as subtype B. Type 2 have more extensive involvement of the lateral part of the trochlea presenting as one big fragment with or without posterior fracture (subtype A or B, respectively) and type 3 with involvement of the trochlea with more than one fragment generally presenting with a posterior fracture (subtype B) [6].

Low transcondylar fractures present typically in the elderly group with a fracture line proximal to the medial epicondyle to the midportion of the lateral epicondyle and present with the challenge of achieving distal fixation in osteopenic bone.

2.4 Clinical Presentation

Complex injuries may be produced by high-energy injuries in young patients or low-energy injuries in osteopenic patients. As such, other orthopedic injuries must be discarded. The neurovascular status of the limb should be documented including the status of the median, radial, and ulnar nerves. The presence of an open fracture or a compromise of the soft tissues must be assessed because it has been related with worse clinical outcomes and an increase in complications [8]. Previous conditions affecting the elbow joint (rheumatoid arthritis, posttraumatic arthritis, etc.) should be excluded as this may modify the surgical plan.

Orthogonal radiographic views should be obtained to assess the fracture. The presence of a coronal fracture line, more than three articular fragments, metaphyseal comminution, a completely separated articular fragment, or impaction of the articular surface should be considered as a complex pattern of injury. CT scan may improve our understanding of articular fractures; specifically, it may detect the existence of posterior comminution of the trochlea and extension of the fracture into the medial epicondyle. Traction radiographs have been advocated but are seldom used in our practice.

2.5 Management

Distal humerus fractures are difficult to treat. Internal fixation is probably the gold standard of these injuries, except for certain patterns of fractures in selected group of patients (old age, prior joint disease). However, the results of internal fixation may be compromised by the complex pattern of the injury, the loss of bone, and the presence of additional trauma [1].

2.5.1 Supracondylar Fractures

Plating techniques have evolved over the years to include precontoured anatomical plates that facilitate and guide bony reconstruction. The use of parallel plating has gained favor because of improved fixation of the distal fragment and the possibility of metaphyseal compression that may reduce the rates of nonunion [9] (Figs. 2.1 and 2.2).

A posterior midline incision with thick fasciocutaneous flaps is used. The management of the ulnar nerve is controversial. Some authors prefer to identify and decompress the nerve during surgery and leave it in place at the end of the

Fig. 2.1 A supraintercondylar fracture with a low fracture line and comminution of the articular surface in a 59-year-old patient (**a**, **b**) treated with internal fixation with parallel plates through an olecranon osteotomy fixed with a tension band wiring technique (**c**, **d**)

procedure, while others prefer a routine anterior transposition. It is probably wise to individualize each case, but it seems that anterior transposition is at least as safe as leaving the nerve in place. This is probably true as well for total elbow arthroplasty [10, 11].

Complex fractures usually require olecranon osteotomy. These injuries may be very challenging due to articular surface or metaphyseal column comminution. The principles of this surgery include provisional assembly of the articular surface, plate placement and provisional reduction, articular and distal fixation, supracondylar compression, and final proximal plate fixation [12].

Comminution of the articular surface may be an indication for prostheses, but usually if the medial trochlea and the condyle are present, reconstruction can be performed. An intercalary segmental tricortical iliac crest graft can be used between the medial and lateral columns and help support one

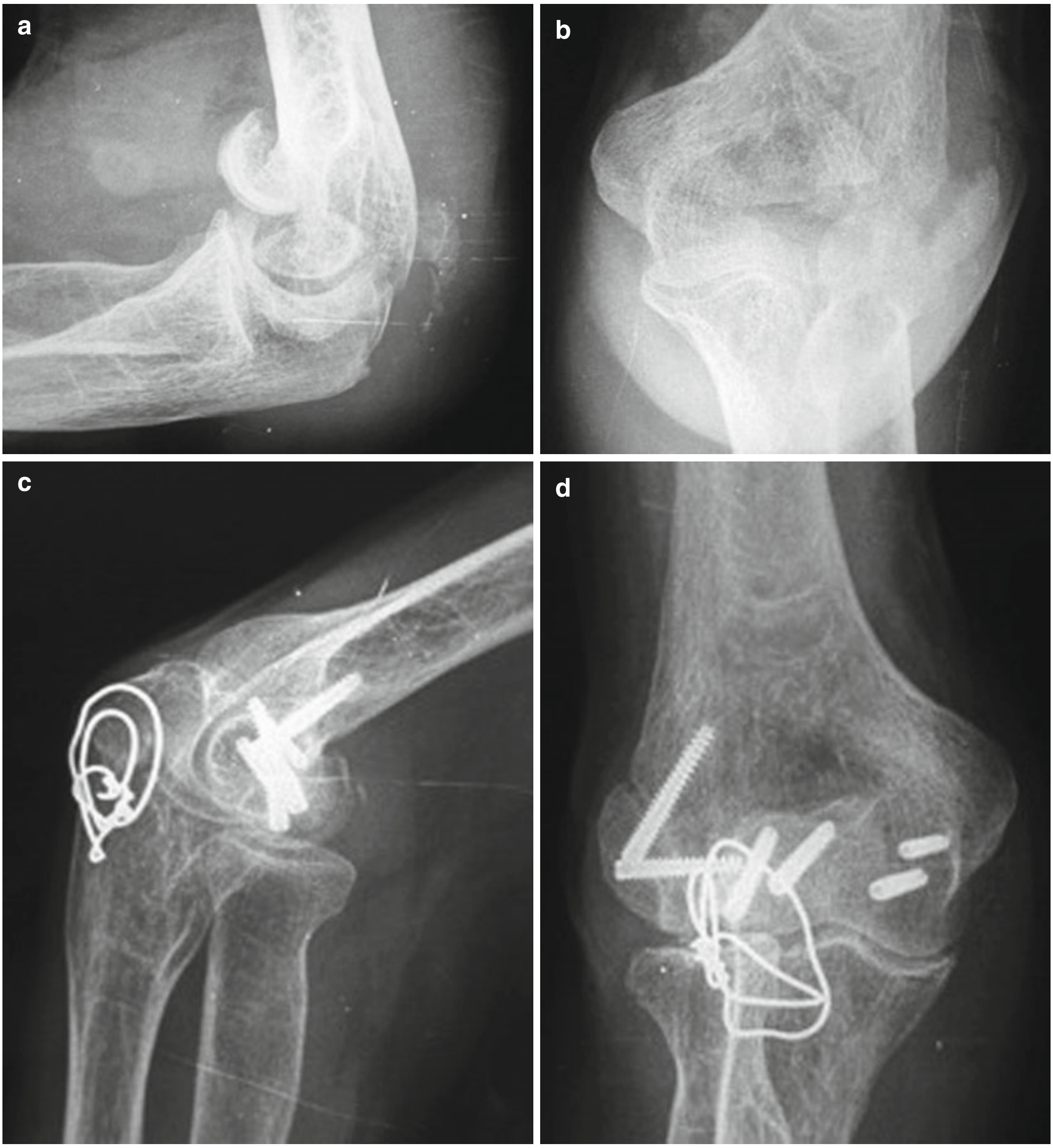

Fig. 2.2 Complex distal articular humerus fracture (**a**, **b**). An extensile lateral approach and variable pitch headless screws were used from anterior to posterior. An associated triceps tendon injury was presented and was treated with tension band wiring (**c**, **d**)

column against the other when internal fixation is performed. Fixation with parallel plating should be then performed engaging the graft with screws from each plate. Metaphyseal comminution can be managed by controlled shortening of the distal humerus in order to achieve metaphyseal compression. Shortening of up to 2 cm is tolerable, without obvious decrease in extensor strength. With shortening, the distal humerus may have to be slightly translated medially or laterally, as needed. Sometimes, precontoured plates need to be recontoured to fit this new situation, but the objective of achieving metaphyseal compression should be fulfilled [13].

There are situations where internal fixation may not be feasible, and elbow arthroplasty can be a good salvage option (Fig. 2.3). Indications would include extensive comminution in the

Fig. 2.3 A complex distal humerus fracture in a 79-year-old patient treated with a linked total elbow arthroplasty: (**a**, **b**) preoperative radiographs; (**c**, **d**) radiographs after total elbow arthroplasty

elderly or cases with previous articular damage [14]. A posterior midline incision is generally used. Thick fasciocutaneous flaps need to be developed to gain access to both the medial and the lateral sides of the humerus. The ulnar nerve management is based on surgeon's criteria, but we generally protect and transpose it anteriorly at the end of the procedure. A bilaterotricipital approach is developed, and the distal fragments are removed after detaching the ligaments and extensor and flexor muscles. The elbow is dislocated and is brought through the medial or lateral side of the triceps to gain access to the distal humerus. The humeral shaft is opened at the top of the olecranon fossa and broached following the specific surgical technique for the used implant. Since the epicondylar axis is absent for referencing the external rotation of the implant, the posterior cortex of the humerus may serve as a valuable reference. Access to the ulna is probably the most difficult part of the procedure because the orientation is hindered by the triceps-on approach. The canal is accessed with the use of a high-speed burr and progressively reamed. The canal is then broached, after which trialing is performed and elbow motion and alignment assessed. The final components are implanted with antibiotic-loaded cement and coupled. The subcutaneous tissue is closed over drains, and the elbow is placed in an extension splint. The elbow is kept in the splint between 2 and 7 days, when active motion exercises are encouraged. A nightly elbow extension splint can be used for 2–4 weeks. Heterotopic ossification therapy with indomethacin is not routinely used in this population.

2.5.1.1 Results/Outcomes

Robinson et al. analyzed 949 fractures treated with "modern" techniques of internal fixation with a mean follow-up of 36 months. They reported a mean arc of motion of 100° with 78 % patients having good or excellent results. Limited motion and residual pain and less strength were common findings [4].

Sanchez-Sotelo et al. reviewed the results of complex supracondylar fractures with the use of parallel-plating principle technique. Twenty-six fractures (81 %) were AO type C3 and 14 (44 %) were open. 97 % achieved union and 84 % patients achieved a satisfactory result. The result was graded as excellent for 11 elbows, good for 16, fair for 2, and poor for 3 using the Mayo Elbow Performance Score. Five patients required surgery for stiffness associated with heterotopic ossification, and one patient presented with deep infection that required surgical debridement. Two patients needed additional procedures to achieve final wound closure. One patient required reoperation for a nonunion. Two patients experienced ulnar neuropathy that resolved without operation (of note, all patients had an anterior transposition of the ulnar nerve). Two patients developed osteoarthritis and one developed avascular necrosis. Open fractures had more pain, worse functional outcomes, and more complications [8].

Kaminemi et al. reported on the outcome of 42 elbows treated with total elbow arthroplasty at a mean follow-up of 7 years showing a mean MEPS of 93. Twenty-nine percent of patients had a complication, and 23 % required revision surgery for any reason [15].

In our own experience treating 16 elbow fractures with a linked elbow arthroplasty at mean follow-up of 4.7 years, patients achieved a mean motion in flexion-extension of 28–117°. The mean MEPS was 73 points (out of a 100) with 31 % of patients showing moderate to severe pain. Complications included sensory ulnar neuropathy in half of the patients, infection in three patients, and humeral loosening in one patient [16].

McKee et al. performed a prospective randomized multicenter trial comparing ORIF with semi-constrained total elbow arthroplasty in patients over 65 years of age. Five patients initially allocated to receive ORIF had to cross over and received TEA because of the unreconstructable nature of the fracture. Outcomes were better for patients receiving an arthroplasty at 2 years. The complication rate was 140 % in the ORIF group and 72 % in the TEA group [17].

2.5.2 Articular Fractures

Often regarded as simple capitellar fractures, experience has shown that these are rarely simple fractures and that they are often complicated by the presence of medial extension into the trochlea and posterior comminution. The most complex situation involves the presence of five individualized fragments, those being the lateral epicondyle, capitellum with an anterior and posterior fragment, the trochlea with an anterior and a posterior impacted fragment, and the medial epicondyle. In this situation an olecranon osteotomy is needed in order to be able to reduce and disimpact the posterior fractures and have access to the medial epicondyle. Bone graft may be needed to augment the fixation, which is generally performed with screws. If the elbow was approached through an olecranon osteotomy, posterior-to-anterior screws are generally preferred. Plates are rarely needed except in cases with extensive posterior comminution or to reconstruct the medial or lateral epicondyle.

In cases without involvement of the medial epicondyle, a lateral approach through the lateral column extending distally through Kaplan's interval may be utilized. When the lateral epicondyle is fractured, the elbow can be hinged open on the medial side in order to gain access to the medial trochlea. In cases without fracture of the lateral epicondyle, the lateral ligament must be explored because it may be injured. Screws inserted from anterior to posterior can be used. Herbert-type screws or differential pitch screws are generally preferred. The screws should be countersunk to avoid damage to the cartilage of the radial head or proximal ulna.

2.5.2.1 Results/Outcomes

Dubberley et al. reported on 28 cases of capitellar and trochlear fractures. Of these, 13 cases were type 3 (capitellar fracture with involvement of the trochlea and more than one fragment generally presenting with posterior fracture). They were generally treated using screws of various types, supplemented with threaded Kirschner wires. Two patients were treated with total elbow arthroplasty and were excluded from the final analysis. At final follow-up, patients with more complex fractures had less grip, flexion, extension, and supination strength, but there was no difference in elbow motion when compared to simpler patterns of injury. Osteonecrosis was only observed in type 3 fractures. Seventy percent of patients had a complication requiring another operation, mainly due to restricted motion. Nine out of thirteen cases had radiographic signs of arthritis. Patients showed 25° of decreased motion in flexion-extension when compared to the unaffected side [6].

Ring et al. reported their experience treating 21 patients with articular fractures of the distal part of the humerus. Eleven of these, with posterior impaction, were regarded as the most complex injuries of this series (types 4 and 5 according to Ring et al. classification). An extensile lateral exposure was used for every case except when the medial epicondyle was affected (type 5). When the medial epicondyle was fractured, an olecranon osteotomy was used. Although the results were not stratified according to the degree of injury, 10 out of 21 patients required a second operation, mainly to address stiffness, ulnar neuropathy, hardware removal, and loss of fixation. The authors found settling of one trochlear fracture, but no cases of osteonecrosis and no signs of arthritis were found. The mean arc of motion was 27° of extension and 123° of flexion with normal pronosupination [5].

Mighell et al. analyzed the results of distal articular humeral fractures. Six of sixteen patients had Ring type 4 injuries. All patients were operated through a lateral approach using headless compression screws from anterior to posterior. Patients achieved a mean arc of motion of 126°, and all patients achieved good or excellent results. No patients required a reoperation, and two patients showed signs of osteoarthritis [18].

Hughes et al. reported on the outcome of hemiarthroplasty for fractures of the distal humerus following acute or chronic trauma in 29 patients. Patients achieved a functional arc of motion with better pain scores in patients treated acutely. The requisite for the use of a hemiarthroplasty is that the supracondylar columns are not fractured or they are reconstructable, an intact or stable radial head and coronoid, and competent medial and lateral ligaments. If one of the latter is absent, a total elbow arthroplasty is probably better as previously mentioned [19].

2.5.3 Low Transcondylar Fractures

These fractures generally affect elderly patients. The fracture line is usually proximal to the medial epicondyle and extends to the midportion of the lateral epicondyle without extension into the joint line. Fractures with a higher fracture line are managed with internal fixation.

The challenge in these fractures is the quality and amount of bone in the distal fragment to allow purchase with internal fixation. Since the requirements of this population are to gain rapid return to their low-demand daily activities, total joint arthroplasty may be an option and can be performed without disruption of the extensor mechanism. Although some authors have used a hemiarthroplasty in this population with good results, this indication is limited in the available literature, and total elbow arthroplasty is usually preferred [15, 19, 20].

Conclusions

Distal humerus fractures are difficult fractures to treat and have a high rate of complications. These fractures should probably be treated in specialized centers. Internal fixation is the gold standard for the majority of these injuries. It is usually necessary to perform additional surgical gestures during surgery, including soft-tissue procedures, bone augmentation or grafting, bone remodeling, and nerve release, which increases the complexity of these injuries. The use of an elbow arthroplasty may be beneficial in the elderly or in patients with previous joint disease. Patients should be counseled that appropriate treatment may render a functional painless elbow but may need additional procedures and extensive rehabilitation.

References

1. Sanchez-Sotelo J (2012) Distal humeral fractures: role of internal fixation and elbow arthroplasty. J Bone Joint Surg Am 94:555–568
2. Kim SH, Szabo RM, Marder RA (2012) Epidemiology of humerus fractures in the United States: nationwide emergency department sample, 2008. Arthritis Care Res (Hoboken) 64:407–414
3. Palvanen M, Niemi S, Parkkari J, Kannus P (2003) Osteoporotic fractures of the distal humerus in elderly women. Ann Intern Med 139:W1–W61
4. Robinson CM, Hill RM, Jacobs N, Dall G, Court-Brown CM (2003) Adult distal humeral metaphyseal fractures: epidemiology and results of treatment. J Orthop Trauma 17:38–47
5. Ring D, Jupiter JB, Gulotta L (2003) Articular fractures of the distal part of the humerus. J Bone Joint Surg Am 85-A:232–238
6. Dubberley JH, Faber KJ, Macdermid JC, Patterson SD, King GJ (2006) Outcome after open reduction and internal fixation of capitellar and trochlear fractures. J Bone Joint Surg Am 88:46–54
7. Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA et al (2007) Fracture and dislocation classification compendium – 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma 21(10 Suppl): S1–S133
8. Sanchez-Sotelo J, Torchia ME, O'Driscoll SW (2007) Complex distal humeral fractures: internal fixation with a principle-based parallel-plate technique. J Bone Joint Surg Am 89:961–969
9. Shin SJ, Sohn HS, Do NH (2010) A clinical comparison of two different double plating methods for intraarticular distal humerus fractures. J Shoulder Elbow Surg 19:2–9
10. Chen RC, Harris DJ, Leduc S, Borrelli JJ Jr, Tornetta P 3rd, Ricci WM (2010) Is ulnar nerve transposition beneficial during open reduction internal fixation of distal humerus fractures? J Orthop Trauma 24: 391–394
11. Vazquez O, Rutgers M, Ring DC, Walsh M, Egol KA (2010) Fate of the ulnar nerve after operative fixation of distal humerus fractures. J Orthop Trauma 24: 395–999
12. Sanchez-Sotelo J, Torchia M, O'Driscoll SW (2001) Principle-based internal fixation of distal humerus fractures. Tech Hand Up Extrem Surg 5:179–187
13. O'Driscoll SW, Sanchez-Sotelo J, Torchia ME (2002) Management of the smashed distal humerus. Orthop Clin North Am 33:19–33
14. Cobb TK, Morrey BF (1997) Total elbow arthroplasty as primary treatment for distal humeral fractures in elderly patients. J Bone Joint Surg Am 79:826–832
15. Kamineni S, Morrey BF (2004) Distal humeral fractures treated with noncustom total elbow replacement. J Bone Joint Surg Am 86-A:940–947
16. Antuña SA, Laakso RB, Barrera JL, Espiga X, Ferreres A (2012) Linked total elbow arthroplasty as treatment of distal humerus fractures. Acta Orthop Belg 78:465–472
17. McKee MD, Veillette CJ, Hall JA, Schemitsch EH, Wild LM, McCormack R et al (2009) A multicenter, prospective, randomized, controlled trial of open reduction–internal fixation versus total elbow arthroplasty for displaced intra-articular distal humeral fractures in elderly patients. J Shoulder Elbow Surg 18:3–12
18. Mighell M, Virani NA, Shannon R, Echols EL Jr, Badman BL, Keating CJ (2010) Large coronal shear fractures of the capitellum and trochlea treated with headless compression screws. J Shoulder Elbow Surg 19:38–45
19. Hughes J (2012) Fractures of the distal humerus: distal humerus arthroplasty. In: Stanley D, Trail I (eds) Operative surgery of the elbow. Churchill-Livingstone, London, pp 279–289
20. Adolfsson L, Nestorson J (2012) The Kudo humeral component as primary hemiarthroplasty in distal humeral fractures. J Shoulder Elbow Surg 21:451–455

3 Fracture-Dislocations of the Elbow

Eduard Alentorn-Geli, Xavier Espiga, Raúl Barco, and Samuel A. Antuña

3.1 Introduction

The elbow comprises the ulnohumeral, radiohumeral, and proximal radioulnar joints. The most important joint for the overall stability of the elbow in any plane is the ulnohumeral joint [1]. The principal structures participating in elbow stability are the coronoid process, collateral ligaments, olecranon, and radial head. The stability in the sagittal plane is essentially provided by the coronoid process and olecranon by serving as a buttress to anteroposterior displacement, essentially with elbow flexion [1]. In extension, the anterior displacement is prevented by the olecranon, whereas the collateral ligaments prevent posterior displacement. Experimental data have demonstrated that resection of more than 50 % of the coronoid process results in a highly unstable elbow, especially when combined with injury to the radial head or collateral ligaments [1].

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The coronoid process of the ulna is one of the most important stabilizers of the elbow. Regan and Morrey classified these fractures into three types depending on the size of the fragment type I is an avulsion of the tip of the coronoid process; type II is a fragment <50 % of the coronoid process; and type III is a fragment >50 % of the coronoid process [2]. Each type was further divided to include whether the fracture was associated (A) or not (B) to elbow dislocation [3]. The most unstable injury pattern is type III, especially IIIB, which requires fixation in virtually all cases. The degree of instability in type II fractures depends on the size of the fragment but also on the associated injuries. Specific characteristics of type II fractures will guide the management strategy.

Bony structures involved in varus/valgus stability of the elbow are the anteromedial facet of the coronoid process and humeral trochlea for varus stability and the radial head, capitellum, greater sigmoid cavity, and humeral trochlea for valgus stability. Altogether, bony structures provide 50 % of varus/valgus stability in elbow flexion [1].

The radial head (i.e., radiohumeral joint) is a secondary stabilizer because its role in elbow stability only takes place when severe damage to the coronoid process (for anteroposterior displacement) or MCL (for varus/valgus stability) is produced [1].

Among the soft tissue stabilizers, the collateral ligaments are the most critical. The lateral collateral ligament (LCL) complex and medial collateral ligament (MCL) provide varus and valgus stability to the elbow, respectively. The role

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of the collateral ligaments in stability in the coronal plane is provided mainly in flexion, as they have a minor contribution in extension [1]. Thanks to its different bundles, both ligaments also contribute to anteroposterior and rotational stability of the ulnohumeral, radiohumeral, and proximal radioulnar joints.

Stability for the proximal radioulnar joint essentially depends on the annular and quadrate ligaments, and fibers of the anterior bundle of both the LCL and MCL. Anterior and posterior bundles of both collateral ligaments also contribute to anteroposterior stability of the ulnohumeral joint.

Rotational stability of radiohumeral and ulnohumeral joints depends on all bundles of both collateral ligaments, capsule and capsular ligament reinforcements, and bony structures itself. Injury of any of the above-mentioned structures may lead to simple (damage of few stabilizers) or complex (damage of many stabilizers) elbow instability.

3.2 Complex Acute Elbow Instability

Complex acute elbow instability is defined whenever there is elbow instability with a bony injury, usually a combination of a radial head and coronoid fracture. Fracture of the coronoid process should rise suspicious of complex elbow instability because this fracture rarely occurs in isolation [3].

Different patterns of injury have been described: posteromedial, posterolateral, and fracture-dislocations of the proximal ulna. The intra-articular nature of these injuries and the associated damage to the ligaments explain their inherent difficult treatment and suboptimal results [4]. The use of CT scan has increased our understanding of these difficult injuries.

3.2.1 Complex Posterolateral Acute Instability: The Terrible Triad

The "terrible triad" is an elbow injury consisting of elbow dislocation, radial head fracture, and coronoid fracture (Fig. 3.1). It has been termed "terrible" because of poor results and frequent complications associated with these injuries: stiffness, instability, or posttraumatic osteoarthritis, among others [5–11]. It is usually caused by a fall onto an extended elbow with a supinated forearm and a combination of axial- and valgus-directed forces in a posterolateral rotatory instability pattern. The damage begins with avulsion of the lateral ulnar collateral ligament (LUCL). Ligamentous injury along with the supination position favor the fracture and dislocation of the radial head, which is accompanied by tears of other fascicles of the LCL complex [12]. Injury forces then progress to the anterior and posterior capsule and reach the medial collateral ligament: the Horii circle of forces [13, 14]. The elbow usually suffers a subluxation or complete dislocation at this point, which tears the posterior bundle of the MCL and posteromedial capsule and, finally, the anterior bundle of the MCL [14]. The coronoid process may be fractured at any stage by the axial-valgus load or because of the posterior elbow dislocation [14], increasing the posterolateral rotatory instability of this injury [15].

Fractures of the coronoid process have been also classified depending on the location of the injury by O'Driscoll et al.: type I fractures involve the tip; type II, the anteromedial facet; and type III, the base of the coronoid process [16]. This classification system correlates with the mechanisms of injury and has been related to different associated injuries and management strategies [15]. The posterolateral rotatory instability is typically associated with O'Driscoll type I coronoid fracture [15, 17], but may be associated with any type of coronoid fracture [12].

The management of the "terrible triad" involves a careful consideration of each of the damaged structures to achieve successful results (Fig. 3.2). The first important aspect to take into account is the radial head fracture. It is desirable to attempt a stable fixation whenever possible (with screws or plate and screws), but many times it is not possible due to articular damage, metaphyseal comminution or bony impaction. When stable fixation is precluded, the radial head should be replaced to prevent any further destabilizing effect on the elbow from suboptimal osteosynthesis. After the radial head is fixed or

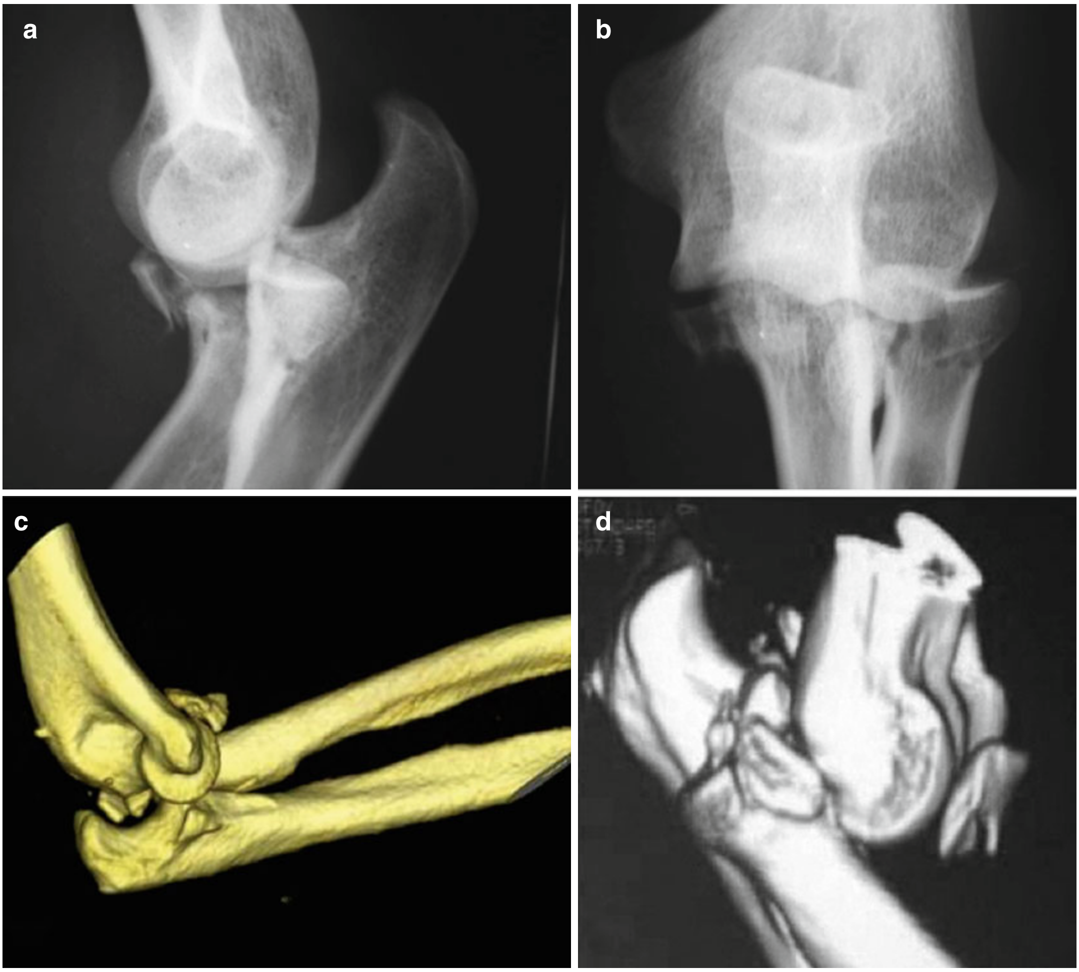

Fig. 3.1 Terrible triad of the elbow: (**a**) plain radiograph with lateral view; (**b**) plain radiograph with anteroposterior view; (**c**) 3D CT reconstruction with lateral view demonstrating intra-articular fragments of the radial head; (**d**) 3D CT reconstruction with lateral view

replaced, the LCL complex is repaired through the same approach with a high-strength suture with locking stitches fixed to the isometric point just distal to the epicondyle.

Internal fixation of the coronoid process is advisable in Regan-Morrey type II and probably mandatory in type III fractures. This may be performed with sutures (mainly in the smallest type II fractures), screws, or plate and screws (essentially in larger fragments). Our preference is usually to fix the coronoid with simple screws and avoid bulky plates medially.

After radial head fracture, LCL tear and coronoid fracture are addressed, and careful elbow stability is examined under fluoroscopy. In general, if the elbow remains unstable, the surgeon may use an external fixator or repair the MCL. However, if there is clear valgus instability, the repair of MCL may be advisable. Table 3.1 summarizes the studies involving "terrible triad" injuries [5–11].

3.2.2 Complex Posteromedial Acute Instability

This pattern of injury develops after a varus and posteromedial rotational injury force is applied to

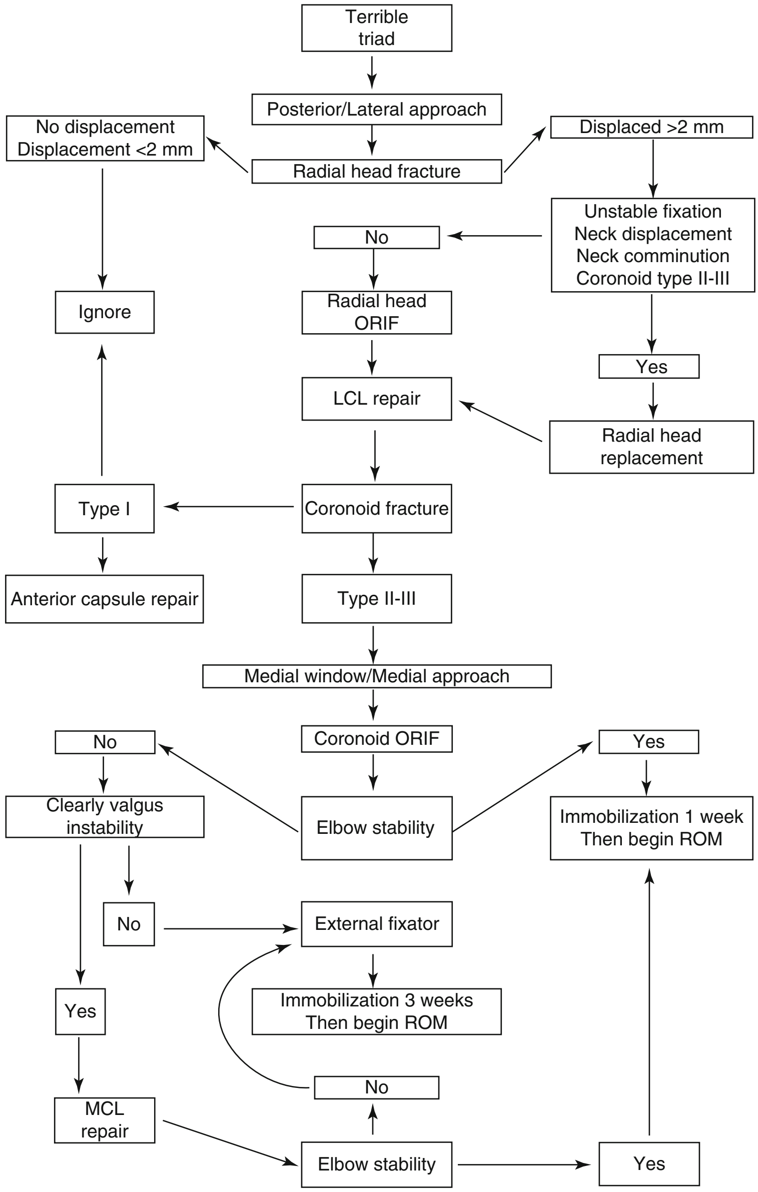

Fig. 3.2 Management algorithm for the "terrible triad": *ORIF* open reduction internal fixation, *LCL* lateral collateral ligament, *ROM* range of motion, *MCL* medial collateral ligament

the elbow [16], following a fall onto an outstretched arm with the forearm in pronation [18]. The varus force causes tearing of the LCL complex and creates a fracture of the anteromedial facet of the coronoid due to an axial- and varus-directed force from the trochlea (shearing mechanism fracture) (Fig. 3.3) [19]. It may be associated with either subluxation or dislocation of the elbow, and it is usually accompanying damage of the ulnohumeral cartilage. The posteromedial rotatory instability pattern is therefore associated with an O'Driscoll type II coronoid fracture [15, 20]. Bone injury to the medial column between the anteromedial facet of the coronoid process and the medial lip of the trochlea creates bony incongruity and instability. The MCL is usually intact; however, it is incompetent because its attachment to the coronoid process has been fractured. The elbow is unstable in the coronal (varus/valgus) plane and also unstable in the sagittal (anteroposterior) plane. The radial head is not typically fractured, but it may be involved in some

Table 3.1 Summary of studies including "terrible triad" injuries

Reference	Patients' characteristics	Treatment	Follow-up	Outcomes	Complications
Ring et al. [5]	N: 11; 6 males, 5 females Mean (range) age 49 years (17–67)	RH: 5 ORIF, 4 excision, 2 non-op Coronoid fixation: none LCL: 3 repairs; MCL: none External fixator: none.	Mean 7 years	Treatment failure: 3; Brosberg/Morrey mean score 76: Excellent 2, Good 2, Fair 3, Poor 1 Mean FE & PS arc 92º and 126º	Instability 5; PTOA 9
Pugh et al. [6]	N: 36; 22 males, 14 females Mean (range) age 41 years (13–76)	RH: 13 ORIF, 20 RHR, 3 excision Coronoid: 18 sutures, 18 screws LCL: 36 repairs; MCL: 6 repairs External fixator: 2.	Mean 34 months	Mean MEPI score 88: Excellent 15, Good 13, Fair 7, Poor 1 Mean FE & PS arc 112º and 136º	RU synostosis 2; Instability 1; PTOA 14; HO 4; Infection 1; Stiffness 4
Egol et al. [8]	N: 29; 15 males: mean (range) age 49 years (28–68); 14 females: mean (range) age 57 years (32–79)	RH: 8 ORIF, 15 RHR, 3 excision, 3 non-op Coronoid: 5 screws, 24 non-op LCL: 29 repairs; MCL: 0 repairs External fixator: 13	Mean 27 months	Brosberg/Morrey mean score 77; Mean MEPI 81; Mean DASH 28 Mean FE & PS arc 109º and 128º	PTOA 22; HO 10; Ulnar neuropathy 3; Stiffness 4; 1 RHR loosening; Instability 1; CRPS 1
Forthman et al. [7]	N: 22; 14 males, 8 females Mean (range) age 48 years (24–75); all type II coronoid fractures; RH: 10 type II, 12 type III	RH: 1 ORIF, 20 RHR, 1 allograft Coronoid: all sutures; & screw in 3 LCL: 22 repairs; MCL: none External fixator: none.	Mean 29 months	Brosberg/Morrey mean score 88: Excellent 6; Good 11; Fair 3, Poor 2; Mean FE 134/17 and PS 75/62	PTOA 7; Ulnar neuropathy 4; HO 4; Instability 1
Lindenhovius et al. [10]	N: 18; 12 males, 6 females Mean (range) age 47 years (22–76)	RH: 1 ORIF, 17 RHR Coronoid: all sutures; & screw in 2 LCL: 18 repairs External fixator: none.	Mean 29 months	Brosberg/Morrey mean score 90: Excellent 5, Good 10, Fair 3; Mean DASH 15; Mean MEPI 88 Mean FE 135/17º; Mean PS 78/63º	PTOA 12; Ulnar neuropathy 4; HO 1; Stiffness 1; Wound infection 1
Zeiders and Patel [9]	N: 32. Details on demographic characteristics not provided.	RH: 7 ORIF, 19 RHR, 6 intact Coronoid: sutures LCL: 30 repairs; MCL: 14 External fixator: 21.	Mean 3 years	DASH mean score 23 All functional arc from 130/30º; Mean extension loss 12º, mean flexion loss 14º	HO 3
Chemama et al. [11]	N: 22; 15 males, 7 females. Mean (range) age 46 years (26–75)	RH: 7 ORIF, 4 RHR, 2 excisions, 1 non-op Coronoid: 3 sutures, 3 screws, 1 resection, 7 non-op External fixator: none.	Mean 63 months	Mean MEPI 87: Excellent 4, Good 14 (8 unavailable at follow-up). Mean FE 127/18º; Mean PS 70/64º	PTOA 1; Instability 1; Painful RHR 1

CRPS complex regional pain syndrome, *DASH* Disabilities of the arm, shoulder, and hand, *FE* flexion-extension, *HO* heterotopic ossification, *LCL* lateral collateral ligament, *MCL* medial collateral ligament, *MEPI* Mayo Elbow Performance Index, *N* number of patients, *non-op* non-operative, *ORIF* open reduction internal fixation, *PS* pronation-supination, *PTOA* post-traumatic osteoarthritis, *RH* radial head, *RHR* radial head replacement, *RU* radioulnar

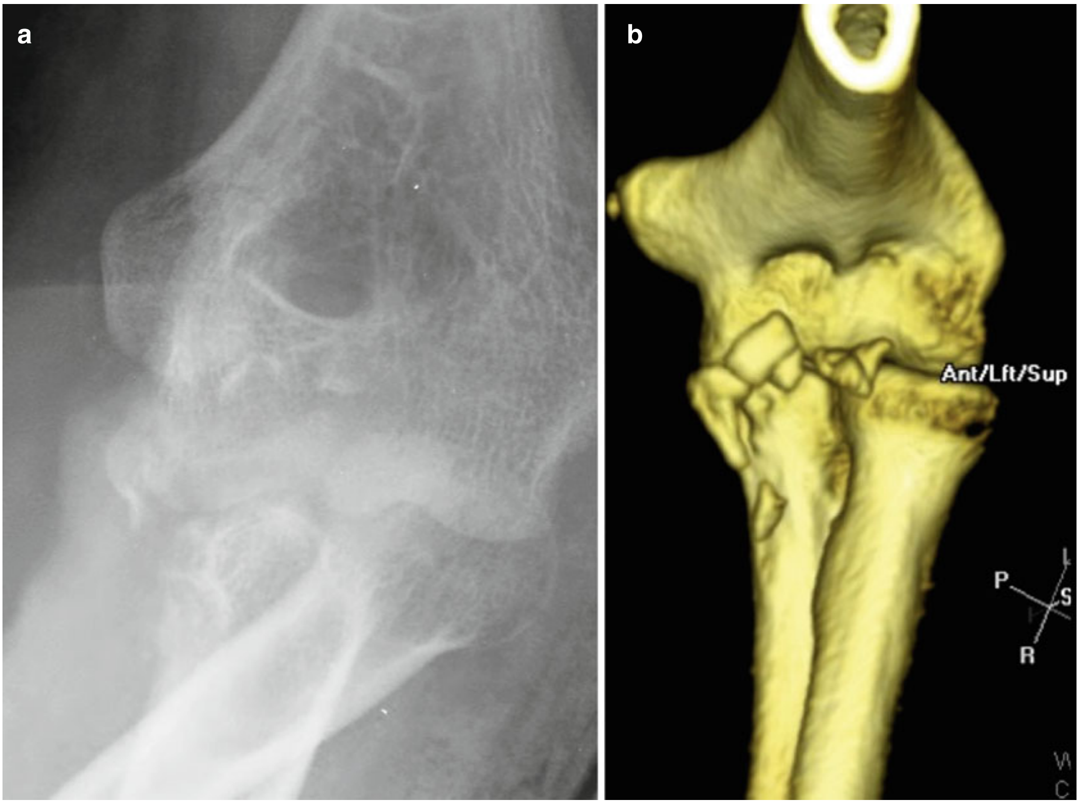

Fig. 3.3 Fracture of the anteromedial facet of the coronoid process: (**a**) plain radiograph with anteroposterior view; (**b**) 3D CT reconstruction with caudal view

cases if elbow dislocation occurs. Because of the recent recognition of this pattern of injury, there are still only very few studies reporting on the results of treatment. Excluding short case series, case reports, and non-English publications, there is only one relevant report on this injury pattern. Doornberg and Ring published the results of 18 patients (mean age 49 years, range 18–85) treated for fracture of the anteromedial facet of the coronoid process over a 6-year period (12 of them were treated in the acute setting and 6 were initially treated elsewhere) [21]. According to the O'Driscoll classification system for coronoid fractures [16], the injury characteristics of the 18 patients were fracture of the anteromedial facet in 16 (subtype I in 1 patient, subtype II in 3 patients, and subtype 3 in 13 patients) and fracture of the base of the coronoid process in 2 (type III). Fifteen patients had avulsion of the origin of the LCL complex from the lateral epicondyle [21]. Three patients were initially treated nonoperatively, and the remaining 15 patients were treated with medial buttressing plates in nine cases, and a screw and sutures in one patient each. The coronoid fracture was not repaired in the remaining seven patients. At an average of 26 months of follow-up after the injury, six patients had malalignment of the anteromedial facet with varus subluxation of the elbow. In four of them, the fragment had not been specifically treated, and in two of them there was a loss of fracture fixation. All six patients developed signs of osteoarthritis and had poor results. In contrast, the remaining 12 patients (nine with fixation of the coronoid fracture) had good or excellent elbow function [21]. The authors recommended to securely fix the coronoid fracture to restore good elbow alignment to increase elbow stability and to decrease the risk of early posttraumatic osteoarthritis.

Internal fixation of coronoid fractures can be achieved with sutures, screws, or plate and screws, depending mainly on the size of the injury and the possibility to obtain a stable fixation. The reconstruction should be, whenever possible, stable enough to begin early range of motion and to prevent elbow stiffness. Reconstruction of the lateral collateral ligaments is advisable as it protects the varus moment of the repaired anteromedial fragment. In cases of tenuous fixation of a small coronoid fragment, protection with an external fixator is advisable.

3.3 Transolecranon Fracture-Dislocations and Complex Monteggia Injuries

This group of injuries comprises the transolecranon fracture-dislocations and Monteggia injuries. Both injuries share the common finding of a proximal ulnar fracture with or without a radial head fracture. In Monteggia lesion, a proximal ulnar fracture is associated with a radial head dislocation, whereas in transolecranon fracture-dislocation the proximal ulnar fracture (which is an olecranon fracture) is associated to a dislocation of both ulna and radius with respect to distal humerus (Fig. 3.4). Therefore, the principal difference between both injuries is the status of the proximal radioulnar joint which is damaged in Monteggia injuries and preserved in transolecranon fracture-dislocations. Specific patterns of injury associate lateral collateral ligament damage.

3.3.1 Transolecranon Fracture-Dislocation

Transolecranon fracture-dislocations occur as a result of a direct trauma over a flexed elbow.

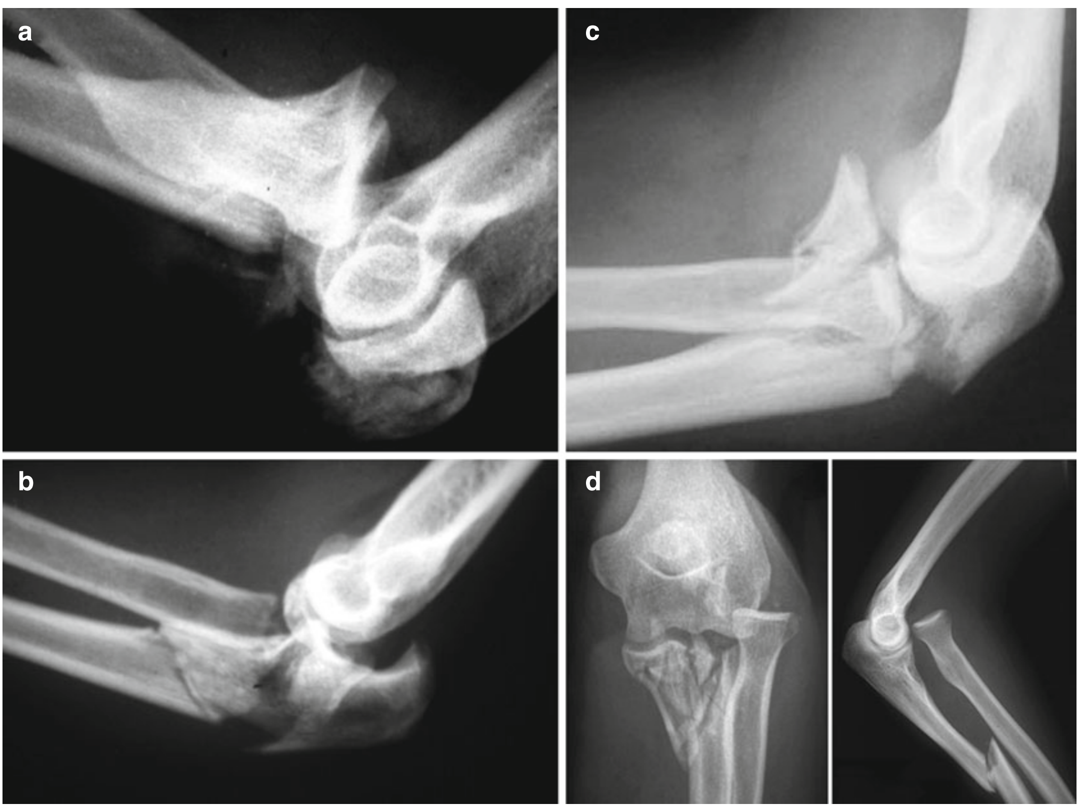

Fig. 3.4 Transolecranon fracture-dislocations and complex Monteggia lesions: (**a**) anterior transolecranon fracture-dislocation of the elbow; (**b**) posterior transolecranon fracture-dislocation of the elbow associated with a radial head fracture; (**c**) complex Monteggia lesion (Bado-Jupiter type IIA); (**d**) complex Bado type III Monteggia lesion (*left*) and original Monteggia fracture-dislocation lesion (*right*) as described by Giovanni Battista Monteggia in 1814

The proximal ulna is fractured at the level of the olecranon, and, depending on the direction of forces, the ulna and radius distal to the olecranon fracture will dislocate anteriorly or posteriorly with respect to the distal humerus. Although the proximal radioulnar joint is not dislocated, some authors have considered that the posterior transolecranon fracture-dislocation is in fact a variant of a Monteggia lesion [22]. Theoretically, in transolecranon fracture-dislocations (either anterior or posterior), the annular and quadrate ligaments remain intact. However, the inclusion of posterior transolecranon fracture-dislocation in the spectrum of Monteggia lesions has been justified by the fact that the former typically has posterior angulation of ulnar apex, radial head fracture, and usually disruption of the LCL [23]. This injury would have been produced by a valgus posterolateral rotatory force with damage to bony more than ligament structures [23].

Depending on the energy of the trauma and the bone quality, the olecranon fracture will be simple or comminuted. In aged osteoporotic individuals, a low-energy trauma may create a complex olecranon fracture. This is the most common type of injury and presents in the form of posterior transolecranon fracture-dislocation [22]. In younger patients with high-energy trauma, posterior transolecranon fracture-dislocations may present as open injuries with involvement of the coronoid process, but this is usually the case of anterior transolecranon fracture-dislocation [24]. This injury was first described by Biga and Thomine as an olecranon fracture (type I or type II depending on the presence of comminution) with anterior dislocation of the proximal ulna and radius [25]. Most of these injuries involve the greater sigmoid notch and the coronoid process and are commonly open injuries due to the high-energy trauma [24]. The radial head and collateral ligaments are commonly spared [15]. Each associated injury must be recognized and treated to prevent poor outcomes. The essential steps in the treatment are to achieve a stable fixation of the ulna and to restore the contour and width of the trochlear notch (anatomic reduction) [4, 26].

The most common fixation method is a posterior precontoured plate and screws with or without bone grafting depending on the degree of comminution [4]. The coronoid process must be fixed with screws through the precontoured plate, and the stability should be checked under fluoroscopy [4]. If the injury is associated with LCL rupture, the ligament should be repaired, especially in cases of residual instability after fracture fixation. As in “terrible triad” injuries, a hinged external fixation should be used whenever a stable internal fixation is not achieved [4]. Table 3.2 summarizes the studies involving anterior and posterior transolecranon fracture-dislocations [22, 24, 26–33].

3.3.2 Complex Monteggia Injuries

Monteggia fracture-dislocation was initially described as a proximal ulnar fracture associated with anterior dislocation of the radial head. The eponym Monteggia injury includes now several patterns of complex fracture-dislocation of the proximal ulna and radius. The common finding is a fracture of the proximal ulna at different levels with dislocation of the proximal radioulnar joint [34]. Bado classified the Monteggia lesion in four groups [35]: type I, fracture of ulnar diaphysis with anterior angulation associated with anterior dislocation of the radial head; type II, fracture of ulnar diaphysis with posterior angulation associated with posterior dislocation of the radial head; type III, fracture of ulnar metaphysis with lateral or anterolateral dislocation of the radial head; and type IV, fracture of the proximal third of the radius and ulna at the same level associated with anterior dislocation of the radial head. Jupiter et al. further classified type II Monteggia lesions [22]: type IIA, ulnar fracture involving the distal olecranon and coronoid process; type IIB, ulnar fracture at the metaphyseal-diaphyseal juncture distal to the coronoid; type IIC, ulnar fracture is diaphyseal; and type IID, complex ulnar fracture extending from the olecranon into the diaphysis. The coronoid fracture involved in types IIB and IID is usually a large fragment corresponding to a type III of either the Regan-Morrey or O’Driscoll classifications [2, 16], thus explaining the characteristic high instability of these injuries.

Table 3.2 Summary of studies including anterior and posterior transolecranon fracture-dislocations and Monteggia lesions

Reference	Injury	Patients' characteristics	Treatment	Follow-up	Outcomes	Complications
Ring et al. [24]	ATOFD	N: 17; 14 males, 3 females Mean (range) age 38 years (18–78) Simple olecranon fracture 3, Complex 14: multifragmentary olecranon 7, large coronoid fragment 7, segmental ulnar fracture 6	ORIF (plate & screws)	Mean 25 months	Broberg/Morrey: Excellent 7; Good 8; Fair 2 Mean FE 127º/14º PS: complete in all but 4.	Implant loosening 1; Implant failure 1; PTOA 2; Pain 3; HO 1
Doornberg et al. [26]	ATOFD	N: 10; 7 males, 3 females Mean (range) age 42 years (20–72) 10 ATOFD (complex ulna in 9), 5 with coronoid fracture (Regan-Morrey III), 1 RH fracture	ORIF: plate & screws 7; TBW 2; sutures 1; 4/5 coronoid fractures fixed; RH fracture was excised	Mean 7 years	Broberg/Morrey: mean score 88; Excellent 4; Good 5; Poor 1 Mean FE 130º/20º Mean PS 80º/75º ASES mean 89	Stiffness 1; PTOA 1; Malunion 2; HO 1; proximal RU synostosis 4
Moushine et al. [27]	ATOFD	N: 14; 6 males, 8 females Mean (range) age 54 years (22–82) Large coronoid fragment: 5	K-wires + TBW 7; Plate and screws 7	Mean 42 months	Broberg/Morrey: Excelent 4; Good 6; Fair 2; Poor 2	Delayed union 3; Instability 0; HO 1, PTOA 4
Lindenhovius et al. [28]	ATOFD	N: 10; Mean (range) age 26 years (16–37); Coronoid fracture 5 (all Regan/Morrey III).	ORIF: Plate & screws 6, TBW 3, other 1	Mean 19 years	Broberg/Morrey: Excellent 5, Good 3, Poor 2; Mean DASH 14; Mean ASES 84; Mean FE arc 123º; Mean PS arc 133º	Ulnar neuropathy 5; PTOA 5
Lindenhovius et al. [28]	PTOFD	N: 10; Mean (range) age 33 years (15–53); Coronoid fracture 6 (2 Regan/Morrey II, 4 type III); RH fractures 8 (5 non-repaired)	ORIF: plate & screws 5, TBW 5	Mean 16 years	Broberg/Morrey: Excellent 8, Fair 1, Poor 1; Mean DASH 3.9; Mean ASES 92; Mean FE arc 120º; Mean PS arc 168º	Ulnar neuropathy 2; PTOA 9
Jupiter et al. [22]	Monteggia	N: 13; 4 males, 9 females Mean (range) age 56 years (28–86) Ulna multifragmentary/comminuted 13; radial head fracture preserved 3	ORIF (plate & screws): additional graft 3 and cerclage 1	Mean 39 months	Function: excellent 3, good 3, fair 4, poor 1, deceased 1. Mean FE 131º/10º Mean PS 69º/61º	Malunion 1; Implant loosening 1; Implant failure 1
Givon et al. [29]	Monteggia	N: 41; 20 males, 21 females; 14 pediatric population, 27 adults Bado I 29 %, II 10 %, III 5 %, IV 12 %, I equivalent 44 %	Children: close reduction 8, open reduction 1 CRIF 4, ORIF 1. Adults: ORIF 22, bone graft in 2	Children 5,4 years Adults 5 years	Motion score: children 99,1, adults 78,3 Figgie score: children 93, adults 66	Ulnar nonunion 6; elbow stiffness 3; osteomyelitis 1

(continued)

Table 3.2 (continued)

Reference	Injury	Patients' characteristics	Treatment	Follow-up	Outcomes	Complications
Ring et al. [30]	Monteggia	N: 48; 23 males, 25 females Mean (range) age 52 years (18–88) Bado I 14 %, II 80 %, III 2 %; IV 4 %. Radial head fracture 26, large single coronoid fragment 10.	TBW & screw 3; Steinmann pin 1; ORIF plate & screws 44; radial head: excision 12, ORIF 10.	Mean 6.5 years	Broberg/Morrey: mean 86; Excellent 18; Good 12; Fair 2; Poor 6. Mean FE 128°/-16° Mean PS 65°/63°	Implant loosening 5; implant migration 1; proximal RU synostosis 3; ulnar malunion 3, PL rotatory instability 1, distal RU instability 1.
Doornberg et al. [26]	Monteggia	N: 16; 8 males, 8 females Mean (range) age 53 years (21–82) All Bado II (except 1 with UH dislocation), all with coronoid fracture (Regan-Morrey III in 15), 13 RH fracture	ORIF: plate & screws in 15, TBW in 1.	Mean 6 years	Broberg/Morrey: mean score 79; Excellent 5; Good 7; Fair 1; Poor 3 Mean FE 125°/30° Mean PS 60°/55° ASES mean 78	Ulnar malunion 1; Ulnar nonunion 1; PTOA 9; RU synostosis 3, UH instability 1
Egol et al. [31]	Monteggia	N: 20; 7 males, 13 females Mean (range) age 52 years (18–83) Bado I 25 %, II 65 %, III 10 %; 3 coronoid fractures (2 of them Regan-Morrey III); 5 radial neck fractures, 4 RH fractures	ORIF: plate & screws in all; screws for RH in 2, plate & screws 1, RH prosthesis 4.	Mean 2.3 years	Broberg/Morrey: mean score 79; Excellent 8; Good 3; Fair 4; Poor 5 Mean FE 120°/25° Mean PS 50°/55°	UH Instability 3; Ulnar nonunion 2; painful hardware 2; HO 7; PTOA 14
Strauss et al. [32]	Monteggia	N: 17; 5 males, 12 females Mean (range) age 55 years (18–83) All Bado II injuries (only non-dislocated patients considered)	Not reported	Mean 29 months	Broberg/Morrey: mean score 82; Excellent 6; Good 4; Fair 6; Poor 1; DASH mean 23 Mean FE 127°/5°; Mean PS 60°/67°	Instability none; PTOA 11; HO 2.
Konrad et al. [33]	Monteggia	N: 47 (Bado I 15, Bado II 27, Bado III 3, Bado IV 2); 30 males, 17 females Mean age (years): Bado I 40, Bado II 43, Bado III 26; Bado IV 35	ORIF: plate & screws in all Bado I, III, and IV; 11 with Bado II had TBW, rest with plate & screws	Mean 8.4 years	Results compared between subtypes. Overall: Broberg/Morrey: Mean score 87; Excellent 22, Good 12, Fair 9, Poor 4; Mean DASH 17	Nonunion 6; Wound infection 2; Fixation failure 2; Proximal RU synostosis 2; PTOA: UH 21, RH 18, Proximal RU 28

ASES American Shoulder and Elbow Surgeons, *ATOFD* anterior transolecranon fracture-dislocation, *CRIF* closed reduction internal fixation, *DASH* Disabilities of the arm, shoulder and hand, *FE* flexion-extension, *HO* heterotopic ossification, *N* number of patients, *ORIF* open reduction internal fixation, *PS* pronation-supination, *PTOA* post-traumatic osteoarthritis, *PTOFD* posterior transolecranon fracture-dislocation, *RH* radial head, *RU* radioulnar, *TBW* tension band wiring, *UH* ulnohumeral

The spectrum of Monteggia lesion includes injuries to the most important bone structures for elbow stability: olecranon, coronoid, and radial head. Giannicola et al. summarized the spectrum injuries commonly found in the Monteggia-like pattern: ulnar fracture, radiohumeral dislocation, ulnohumeral dislocation, proximal radioulnar dislocation, radial head fracture, and distal radio-ulnar joint or interosseous membrane lesion [4]. In summary, Monteggia fracture-dislocation or Monteggia-like lesions are complex injuries affecting several stabilizers of the elbow from both bone and ligament components.

The gold standard for the treatment of Monteggia injury is open reduction and internal fixation of the ulna (and radius in Bado type IV injuries) with a posterior precontoured plate and screws trying to achieve anatomic reduction in terms of length and rotational alignment [4, 34]. Adequate management of basal coronoid fractures and fractures of the anteromedial facet of the coronoid process and fractures involving the crista supinatoris is essential to achieve adequate function of the MCL and LCL, respectively, and, therefore, a stable reconstruction [4, 34]. Small fragments of the coronoid may be fixed with sutures [34]. In cases of sigmoid notch comminution, use of bone graft in conjunction with an angular stable construct of the olecranon is recommended to sustain the articular surface, achieve a stable fixation [4], and decrease the risk of early onset posttraumatic osteoarthritis due to articular incongruence. If the radial head is fractured, fixation instead of excision is recommended to prevent proximal migration of the radius, especially in injuries where the interosseous membrane may have been damaged [4]. Open reduction and internal fixation of ulnar fractures usually allows reduction of the radial head [34]. In cases where the radial head cannot be reduced or remains unstable, exposition of the radiohumeral joint is needed to discard soft tissue interposition and/or to repair the LCL complex [4, 34]. Anatomic reduction of ulnar fractures is essential to manage the radial head, as any shortening or mal-reduction of the ulna may also prevent reduction of radiohumeral joint [4, 34]. Table 3.2 summarizes the studies involving Monteggia lesions [22, 24, 26–33].

Conclusions

Fracture-dislocations of the elbow are complex and severe injuries with a high potential for complications and suboptimal or poor results. Careful physical exams and adequate imaging studies are essential to understand all injuries and provide satisfactory management. In the "terrible triad," there is an elbow dislocation along with fractures of both radial head and coronoid process, leading to posterolateral rotatory instability. In these injuries, it is essential to treat the LCL tear and the radial head fracture. Coronoid fractures should be fixed in those cases with type II and III fractures which render the elbow unstable after radial head reconstruction.

Varus posteromedial rotatory instability typically has both LCL tear and fracture of the anteromedial facet of the coronoid process, where the MCL attaches. The important aspect of the treatment is to repair the LCL and to fix the coronoid fragment. In transolecranon fracture-dislocations and complex Monteggia injuries, the principal damage lies on bony stabilizers. The standard of care is through precontoured plates and screws with careful assessment of any ligament tear, which will require adequate repair to prevent early failure of the implant or severe complications. An external fixator should be used in all cases with residual instability after appropriate treatment of these injuries. The principles of treatment are to provide a stable fixation of bone fragments and strong repair of ligaments to allow early range of motion to decrease the likelihood of elbow stiffness.

References

1. Morrey BF, O'Driscoll SW (2004) Complex instability of the elbow. In: Morrey BF (ed) The elbow and its disorders. Marbán, Madrid
2. Regan W, Morrey BF (1989) Fractures of the coronoid process of the ulna. J Bone Joint Surg Am 71:1348–1354
3. Adams JE, Hoskin TL, Morrey BF, Steinmann SP (2009) Management and outcome of 103 fractures of the coronoid process of the ulna. J Bone Joint Surg Br 91:632–635

4. Giannicola G, Sacchetti FM, Greco A, Cinotti G, Postacchini F (2010) Management of complex elbow instability. Musculoskeletal Surg 94:S25–S36
5. Ring D, Jupiter JB, Zilberfarb J (2002) Posterior dislocation of the elbow with fractures of the radial head and coronoid. J Bone Joint Surg Am 84:547–551
6. Pugh DM, Wild LM, Schemitsch EH, King GJ, McKee MD (2004) Standard surgical protocol to treat elbow dislocations with radial head and coronoid fractures. J Bone Joint Surg Am 86:1122–1130
7. Forthman C, Henket M, Ring D (2007) Elbow dislocation with intra-articular fracture: the results of operative treatment without repair of the medial collateral ligament. J Hand Surg Am 32:1200–1209
8. Egol KA, Immerman I, Paksima N, Tejwani N, Koval KJ (2007) Fracture-dislocation of the elbow. Functional outcome following treatment with standardized protocol. Bull NYU Hosp Jt Dis 65:263–270
9. Zeiders GJ, Patel MK (2008) Management of unstable elbows following complex fracture-dislocations – the “terrible triad” injury. J Bone Joint Surg Am 90(Suppl 4):75–84
10. Lindenhovius ALC, Jupiter JB, Ring D (2008) Comparison of acute versus subacute treatment of terrible triad injuries of the elbow. J Hand Surg Am 33:920–926
11. Chemama B, Bonnevialle N, Peter O, Mansat P, Bonnevialle P (2010) Terrible triad injury of the elbow: how to improve outcomes? Orthop Traumatol Surg Res 96:147–154
12. Dodds SD, Fishler T (2013) Terrible triad of the elbow. Orthop Clin North Am 44:47–58
13. O’Driscoll SW, Jupiter JB, King GJ, Hotchkiss RN, Morrey BF (2001) The unstable elbow. Instr Course Lect 50:89–102
14. O’Driscoll SW (2004) Dislocations of the elbow. In: Morrey BF (ed) The elbow and its disorders, 3rd edn. Marbán, Madrid
15. Manidakis N, Sperelakis I, Hackney R, Kontakis GM (2012) Fractures of the ulnar coronoid process. Injury 43:989–998
16. O’Driscoll SW, Jupiter JB, Cohen MS, Ring D, McKee MD (2003) Difficult elbow fractures: pearls and pitfalls. Instr Course Lect 52:113–134
17. Steinmann SP (2008) Coronoid process fracture. J Am Acad Orthop Surg 16:519–529
18. Sanchez-Sotelo J, O’Driscoll SW, Morrey BF (2006) Anteromedial fracture of the coronoid process of the ulna. J Shoulder Elbow Surg 15:e5–e8
19. Wang X, Chang S, Yu G (2013) Anteromedial coronoid facet fractures. Eur J Orthop Surg Traumatol 23:251–255
20. Ring D (2006) Fractures of the coronoid process of the ulna. J Hand Surg Am 31:1679–1689
21. Doornberg JN, Ring DC (2006) Fracture of the anteromedial facet of the coronoid process. J Bone Joint Surg Am 88:2216–2224
22. Jupiter JB, Leibovic SJ, Ribbans W, Wilk RM (1991) The posterior Monteggia lesion. J Orthop Trauma 5:395–402
23. Ring D, Jupiter JB (1998) Fracture-dislocation of the elbow. J Bone Joint Surg Am 80:566–580
24. Ring D, Jupiter JB, Sanders RW, Mast J, Simpson NS (1997) Transolecranon fracture-dislocation of the elbow. J Orthop Trauma 11:545–550
25. Biga N, Thomine JM (1974) Trans-olecranon dislocations of the elbow. Rev Chir Orthop Reparatrice Appar Mot 60:557–567
26. Doornberg JN, Ring D, Jupiter JB (2004) Effective treatment of fracture-dislocation of the olecranon requires a stable trochlear notch. Clin Orthop Relat Res 429:292–300
27. Moushine E, Akiki A, Castagna A, Cikes A, Wettstein M, Borens O, Garofalo R (2007) Transolecranon anterior fracture dislocation. J Shoulder Elbow Surg 16:352–357
28. Lindenhovius ALC, Brouwer KM, Doornberg JN, Ring D, Kloen P (2008) Long-term outcome of operatively treated fracture-dislocations of the olecranon. J Orthop Trauma 22:325–331
29. Givon U, Pritsch M, Levy O, Yosepovich A, Amit Y, Horoszowski H (1997) Monteggia and equivalent lesions. A study of 41 cases. Clin Orthop Relat Res 337:208–215
30. Ring D, Jupiter JB, Simpson NS (1998) Monteggia fractures in adults. J Bone Joint Surg Am 80: 1733–1744
31. Egol KA, Tejwani NC, Bazzi J, Susarla A, Koval KJ (2005) Does a Monteggia variant lesion result in a poor functional outcome? A retrospective study. Clin Orthop Relat Res 438:233–238
32. Strauss EJ, Tejwani NC, Preston CF, Egol KA (2006) The posterior Monteggia lesion with associated ulnohumeral instability. J Bone Joint Surg Br 88:84–89
33. Konrad GG, Kundel K, Kreuz PC, Oberst M, Sudkamp NP (2007) Monteggia fractures in adults. Long-term results and prognostic factors. J Bone Joint Surg Br 89:354–360
34. Eathiraju S, Mudgal CS, Jupiter JB (2007) Monteggia fracture-dislocations. Hand Clin 23:165–177
35. Bado JL (1967) The Monteggia lesion. Clin Orthop 50:71–86

4 Complex Fractures of the Distal Radius

José Manuel Martínez-Díez

4.1 Introduction

Knowledge of distal radius anatomy is critical to planning surgery. The articular distal radius surface is typically tilted with 22° of radial inclination, 11° of volar tilt, and 12 mm of radial height. The radiocarpal joint is composed of the lunate fossa and the triangular scaphoid fossa. On the ulnar aspect of the distal radius, the sigmoid notch articulates with the distal ulna to form the distal radioulnar joint (DRUJ). It is a pivot that permits pronation and supination of the wrist. The triangular fibrocartilage complex stabilizes the DRUJ. The distal ulna does not articulate with the carpal bones.

For years distal radius fractures were assumed to warrant no more than a cast following Colles' report [1]. Volar and dorsal approaches are used for distal radius fractures. The standard volar radial approach allows the volar surface of the distal radius to be accessed through the interval between the flexor carpi radialis (FCR) tendon and the radial artery. The extended FCR approach allows access to dorsally comminuted and displaced distal radius fractures from a volar approach. Pronating the proximal fragment of the radius out of the way will allow us to visualize the dorsal aspect of the distal radius. The longitudinal dorsal approach has several advantages, including access to the dorsal aspect of the distal radius, the radiocarpal and radioulnar joints, the carpal bones, and the extensor tendons. Important landmarks are the Lister's tubercle, the lunate fossa, the long finger metacarpal, and the radial and ulnar styloids. Access to most dorsal structures of the dorsal wrist, including the distal radius and midcarpus, can be achieved between the third and fourth dorsal compartments.

4.2 Classifications

Classification systems are used to categorize injuries and direct treatment. They should provide a reproducible diagnosis with intra- and interobserver reliability and offer prognostic considerations. There are multiple classifications for distal radius fractures. No one is adequate because there are a large number of variables to be considered regarding the fracture characteristics. To be effective a classification system must categorize the fracture pattern and the severity of the injury, which can be used as a guideline for treatment and prognosis.

4.2.1 Gartland and Werley

In 1951, Gartland and Werley brought attention to a high percentage of poor results of distal radius fracture [2]. An evaluation system was created and it included intra-articular fractures

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and their implications. Most distal radius fractures had an intra-articular pattern, and one third of patients had unsatisfactory results. Posttraumatic arthritis affected 20 % of their series.

4.2.2 Lidstrom

The Lidstrom classification, published in 1959, was based on the fracture line, the direction and degree displacement of distal fragment, and the intra-articular or DRUJ involvement [3].

4.2.3 Frykman

Frykman introduced ulnar involvement in distal radius fracture [4]. The classification identified radioulnar joint injury and the presence or absence of ulnar styloid process. This system does not quantify the direction of initial fracture, comminution, or shortening, and it is very limited to predict prognosis.

4.2.4 Melone

Most recent systems have focused on identifying intra-articular fragments. Melone observed that there were four components at the radiocarpal joint [5]. It includes the radial shaft, the radial styloid, the dorsal medial fragment, and the palmar medial fragment. The extent and direction of these fragments form the basis of this classification. There are five basic fracture patterns.

4.2.5 Jenkins

In 1989, Jenkins added the direction of the fracture line and the degree of comminution to Malone's classification [6].

4.2.6 McMurtry and Jupiter

In 1990, McMurtry and Jupiter defined intra-articular fracture when it extended into the radioulnar or the radiocarpal joints and was displaced more than 1 mm [7].

4.2.7 Mayo Clinic

The Mayo Clinic developed another classification focusing on intra-articular patterns [8]. This system includes the specific articular surfaces of the distal radius.

4.2.8 AO/ASIF

The Association for the Study of Internal Fixation group developed a comprehensive system that serves as a basis for treatment and prognosis [9]. A number designates each bone or segment. The basic types of fractures are extra-articular (A), simple intra-articular (B), and complex intra-articular (C).

4.2.9 Fernández

In 1993 Fernández developed a complex system that is able to recognize the mechanism of injury by observing the fracture pattern [10]. It is a practical classification for determining stability and associated injuries.

4.3 Indications for Surgery

The treatment plan for patients with distal radius fractures can be broken down broadly into the following criteria: fracture pattern, fracture stability, and other situations.

4.3.1 Fracture Pattern

For extra-articular distal radius fractures, the goal is to reduce the fracture to the normal radiographic parameters and maintain them until the fracture heals. Biomechanical studies have helped define the acceptable radiologic parameters of reduction. Loss of radial inclination or radial shortening causes increase in stress across the lunate facet and disruption of distal radioulnar mechanics and distortion of the triangular fibrocartilage complex [11]. Malunion with angulations greater than 20° dorsally or volarly causes changes in the position of the carpus. Dorsal malunion often results in rotational deformities that can result in pronation and supination deficits [12]. Finally, malposition of a fracture has been shown to accelerate degenerative changes (posttraumatic osteoarthritis) over the long term [13].

For intra-articular distal radius fractures, articular congruity must be assessed in addition to the normal radiographic parameters of the distal radius. Several studies have shown that articular step-off of 1 mm or more can result in late radiocarpal osteoarthritis [10]. The presence of posttraumatic radiocarpal osteoarthritis alone does not necessarily correlate with poor functional outcome [14]. With these variables in mind, guidelines for acceptable closed reduction have been formulated [15]: (1) radial inclination greater than or equal to 15° on posteroanterior view, (2) radial length less than or equal to 5 mm shortening on posteroanterior view, (3) radial tilt less than 15° dorsal or 20° volar tilt on lateral view, and (4) articular incongruity less than or equal to 2 mm of step-off.

4.3.2 Fracture Stability

If a fracture is reduced and the position is within the acceptable parameters of reduction as outlined, the next question is to know whether the fracture is stable. Radiographic signs that should alert the orthopedic surgeon that the fracture is probably unstable and closed reduction will be insufficient include the following [16]: dorsal comminution greater than 50 %, palmar metaphyseal comminution, initial dorsal tilt greater than 20°, initial radial shortening more than 5 mm, intra-articular disruption, associated ulnar fracture, and severe osteoporosis.

4.3.3 Other Situations

Lifestyle, mental attitude, associated medical conditions, and compliance with treatment can help decide a surgical treatment. Open fractures warrant operative management following well-established protocols. Bilateral distal radius fractures and ipsilateral concomitant fractures of the upper extremity also require operative treatment. Acute median nerve dysfunction is not associated with specific fracture patterns of the distal radius. Persistent or worsening symptoms warrant surgical fixation of the fracture and open carpal tunnel release.

4.4 Nonoperative Treatment

Nonoperative treatment of distal radius fractures by reduction and immobilization remains the most common form of treatment. Clinical outcome studies and the biomechanical literature demonstrate that maintenance of palmar tilt (normally 11°), ulnar variance (normally <2 mm), and radial height (normally 12 mm) is probably the most important factor in attaining acceptable patient outcomes [17]. The indications for nonoperative management include patients presenting with a fracture in acceptable position or patients in whom the fracture can be maintained in an acceptable position following reduction. The indications for nonoperative management may be broader in the elderly because the fracture often represents a low-energy fragility fracture with less articular involvement. Adequately reduced distal radius fractures require follow-up radiographs to assess for redisplacement and healing.

Complications associated with this distal radius fractures may be diverse. The most common complication is compression neuropathy. The next most commonly observed complication is malunion. Other complications include residual wrist and hand stiffness, attrition ruptures of the extensor pollicis longus, and complex regional pain syndrome (CRPS).

Despite the large body of literature on the subject, results of the nonoperative management of distal radius fractures remain conflicted. Poor outcomes are more common in malunions and included at least one of the following: DRUJ pain or prominent ulnar styloid, radial deviation of the wrist, dorsal angulation, nerve compression, and posttraumatic osteoarthritis [18].

4.5 Operative Treatment

There are two main types of operative treatment: percutaneous pinning and open reduction and internal fixation (ORIF) with plating.

4.5.1 Percutaneous Pinning

Percutaneous pinning can be an effective option for selected fractures. It may be indicated for younger patients who have reduced or reducible fractures with predicted or proven stability [19]. In elderly osteoporotic patients [20] and in severely comminuted intra-articular fractures [21], this technique yields less favorable results. Fractures without significant shortening, comminution of the volar cortex, and fractures that have failed closed reduction or redisplaced with regard to dorsal angulation are ideal for percutaneous pinning. Potential complications include those previously described for nonoperative treatment as well as those directly attributed to the use of percutaneous pins, such as tendon tethering, injury or rupture, pin migration, nerve injury, and pin site infection.

Some studies have demonstrated no significant difference in outcomes between percutaneous pinning and nonoperative treatment [22]. Percutaneous pinning has also been demonstrated to be as effective as external fixation for unstable distal radius fractures. This technique can provide adequate fracture stability and soft tissue and vascular preservation, in addition to minimal patient morbidity, which may facilitate a more rapid return to function compared with more invasive methods.

4.5.2 Open Reduction and Internal Fixation (ORIF): Plating

Restoration of normal anatomy usually provides a satisfactory result. Malunion of the distal radius has been associated with pain, stiffness, weak grip strength, and carpal instability. Plating ensures more consistent correction of displacement and maintenance of reduction. Over the last years, there has been a trend to operative treatment of these fractures in both the elderly and the young population (Fig. 4.1).

Because of a high rate of complications with dorsal plate placement, volar fixation has become the standard approach for distal radius fractures [23]. Volar buttress plates are the traditional plate designs used to treat distal radius volar shear fractures. In normal bone, or even osteoporotic bone without comminution, a locked device provides no advantage and a normal buttress plate can be used.

Fixed-angle locking plate designs have improved strength characteristics compared with traditional nonlocking plates to resist angular motion. Polyaxial locking plates allow an independent trajectory to be selected for each distal screw. The locking nature of the screw-plate construct produces fixation even in bone defects and osteopenic bone and permits early range of motion exercises.

Fixation with a volar fixed-angle device should permit earlier and more aggressive rehabilitation and more rapid regain of function when compared with stabilization with external fixation or percutaneous pinning. Another advantage of a locked plate is the ability to perform indirect reduction.

Most implants currently used to treat distal radius fractures are made either of stainless steel or of titanium alloys. The most commonly used titanium alloys used today are Ti-6Al-7Nb and Ti-6Al-4V. These alloys display excellent corrosion resistance, biocompatibility, decreased implant stiffness, and diminished stress shielding compared with stainless steel [24].

Although the advent of volar locking plates for treating distal radius fractures may seem like a panacea, their use is not without complications. Reports of the complications of volar plates are beginning to appear in the literature [25].

4.6 Complications

The reported complication rates of distal radius fractures in the literature vary from 6 to 80 % [26]. The median nerve is most frequently involved,

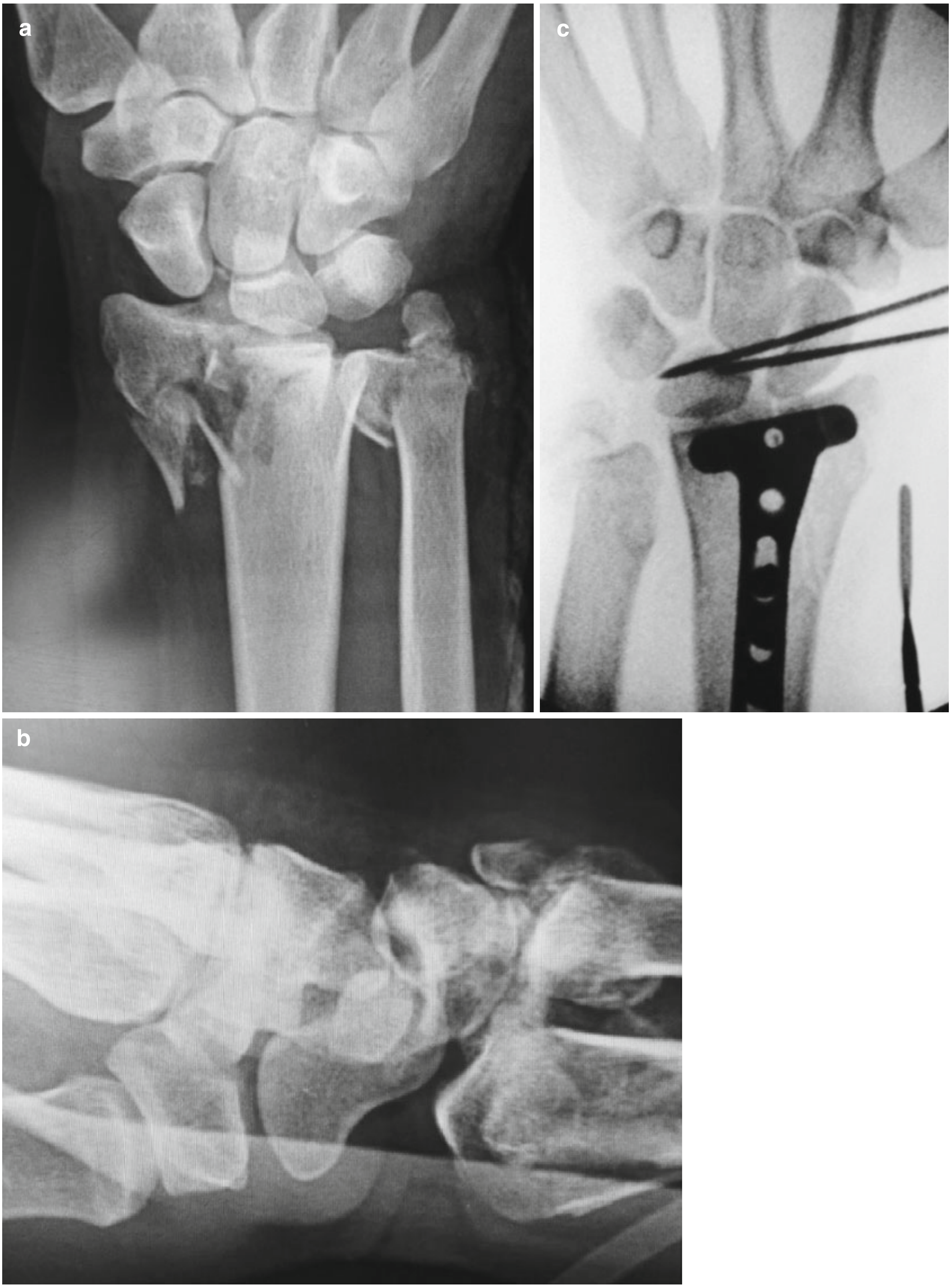

Fig. 4.1 Intra-articular fracture of the distal radius with an associated scapholunate dislocation treated by means of ORIF with LCP 2.4/2.7 volar plate and K-wires at carpal injury: (**a**) anteroposterior preoperative view, (**b**) lateral preoperative radiograph, (**c**) anteroposterior postoperative radiograph, (**d**) lateral radiograph after surgery

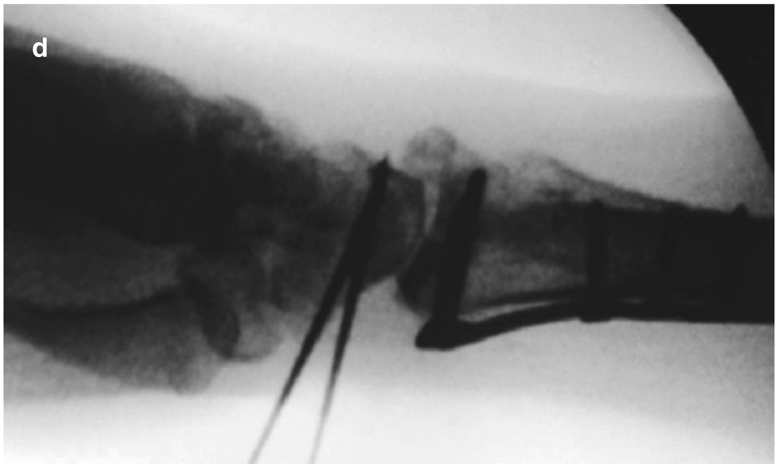

Fig. 4.1 (continued)

followed by the radial and ulnar nerves. Acute carpal tunnel syndrome is more common in patients who have more severe and comminuted fractures and also in those undergoing multiple closed reduction attempts [27]. Carpal tunnel symptoms are common and usually related to swelling and contusion. A carpal tunnel release should be considered if the symptoms are more severe or progressive. Open fractures of the distal radius are infrequent. However, open fractures of the distal ulna in association with a distal radius fracture are more common. Compartment syndrome is a rare complication, but can have dramatic consequences. Young male patients are most at risk because they are more likely to have sustained a high-energy injury. Many factors have been associated with an increased risk for displacement, including increasing age, dorsal comminution, and degree of dorsal angulation at presentation [28].

Compound fractures and fractures treated operatively are at risk for infection. Infection rate with K-wire fixation has been reported to be as high as 33 % [29]. If the wires are left in situ for a prolonged period, the risk for infection increases. Infection with internal fixation is less common. Percutaneous K-wires should not be used to supplement internal fixation because this can act as a pathway for superficial infection to spread to the deeper tissues and bone. The radial nerve sensory branch is particularly vulnerable to injury during K-wire fixation.

Tendon ruptures can occur as an early or late complication. The extensor pollicis longus tendon is most commonly ruptured. CRPS, formerly known as reflex sympathetic dystrophy, has been reported to be more common in the elderly, women, and individuals who have a psychological predisposition.

Years after an intra-articular fracture of the distal radius found that 65 % of patients have radiographic signs of posttraumatic osteoarthritis. Fractures that heal with residual radiocarpal incongruity have a 91 % rate of radiographic osteoarthritis, while fractures that heal with a congruent joint have an 11 % rate [30].

Conclusions

Distal radius fractures are frequent, representing approximately 15 % of all fractures seen in an emergency department. For years distal radius fractures were assumed to warrant no more than a cast following Colles' report. Increasing interest for this fracture is due not only to its high incidence but also to the development of different treatments. Today, the literature is often contradictory regarding the indications for operative and nonoperative management. The goal of treatment for distal radius fractures is to obtain sufficient painless range of motion that will allow the patient to return to daily activities while minimizing the risk of posttraumatic osteoarthritis. Close reduction and casting has historically been the gold standard of treatment. However, operative management may be an option depending on a number of variables such as fracture displacement, fracture stability-associated injuries, and those patient-related.

References

1. Colles A (1814) On the fracture of the carpal extremity of the radius. Edinb Med Surg 10:182–186
2. Gartland JJ, Werley CW (1951) Evaluation of healed Colles' fractures. J Bone Joint Surg Am 33:895–907
3. Lidstrom A (1959) Fractures of the distal end of the radius. A clinical and statistical study of end results. Acta Orthop Scand Suppl 41:1–118
4. Frykman GK (1967) Fracture of the distal radius including sequelae-shoulder hand finger syndrome. Disturbance in the distal radioulnar joint and impairment of nerve function. A clinical and experimental study. Acta Orthop Scand Suppl 108:1–155
5. Melone CP (1984) Articular fractures of the distal radius. Orthop Clin North Am 15:217–236
6. Jenkins NH (1989) The unstable Colles' fracture. J Hand Surg Br 14:149–154
7. Mc Murtry RY, Jupiter JB (1991) Fractures of the distal radius. In: Browner BD, Jupiter JB, Levine AM et al (eds) Skeletal trauma. Saunders, Philadelphia, pp 1063–1094
8. Missakian ML, Cooney WP, Amadio PC et al (1992) Open reduction and internal fixation for distal radius fracture. J Hand Surg Am 17:45–55
9. Muller ME, Nazarian S, Koch P (1987) AO classification of fractures. Springer, Berlin
10. Fernandez DL (1993) Fractures of the distal radius. Operative treatment. Instr Course Lect 42:73–88
11. Fourrier P, Bardy A, Roche G et al (1981) Approach to a definition of malunion callus after Pouteau-Colles fractures. Int Orthop 4:299–305
12. Prommersberger KJ, Froehner SC, Schmitt RR et al (2004) Rotational deformity in malunited fractures of the distal radius. J Hand Surg Am 29:110–115
13. Adams BD (1993) Effects of radial deformity on distal radioulnar joint mechanics. J Hand Surg Am 18:492–498
14. Catalano LW, Cole RJ, Gelberman RH et al (1997) Displaced intra-articular fractures of the distal aspect of the radius. Long-term results in young adults after open reduction and internal fixation. J Bone Joint Surg Am 79:1290–1302
15. Nana AD, Joshi A, Lichtman DM (2005) Plating of the distal radius. J Am Acad Orthop Surg 13:159–171
16. Ruedi TP, Murphy WM (eds) (2000) AO principles of fracture management. Thieme, New York, p 362
17. Kopylov P, Johnell O, Redlund-Johnell I et al (1983) Fractures of the distal end of the radius in young adults: a 30-year follow-up. J Hand Surg Br 18:45–49
18. Altissimi M, Antenucci R, Fiacca C et al (1986) Long-term results of conservative treatment of fractures of the distal radius. Clin Orthop Relat Res 206:202–210
19. Shankar NS, Craxford AD (1992) Comminuted Colles' fractures: a prospective trial of management. J R Coll Surg Edinb 37:199–202
20. Azzopardi T, Ehrendorfer S, Coulton T et al (2005) Unstable extra-articular fractures of the distal radius: a prospective, randomised study of immobilisation in a cast versus supplementary percutaneous pinning. J Bone Joint Surg Br 87:837–840
21. Clancey GJ (1984) Percutaneous Kirschner-wire fixation of Colles' fractures. A prospective study of thirty cases. J Bone Joint Surg Am 66:1008–1014
22. Stoffelen DV, Broos PL (1999) Closed reduction versus Kapandji-pinning for extra-articular distal radial fractures. J Hand Surg Br 24:89–91
23. Jupiter JB, Fernandez DL, Whipple TL et al (1998) Intra- articular fractures of the distal radius: contemporary perspectives. Instr Course Lect 47:191–202
24. Mudgal CS, Jupiter JB (2006) Plate and screw design in fractures of the hand and wrist. Clin Orthop Relat Res 445:68–80
25. Rozental T, Blazar P (2006) Functional outcome and complications after volar plating for dorsally displaced, unstable fractures of the distal radius. J Hand Surg Am 31:359–365
26. McKay SD, MacDermid JC, Roth JH et al (2001) Assessment of complications of distal radius fractures and development of a complication checklist. J Hand Surg Am 26:916–922
27. Bruske J, Niedzwiedz Z, Bednarski M et al (2002) Acute carpal tunnel syndrome after distal radius fractures: long term results of surgical treatment with decompression and external fixator application. Chir Narzadow Ruchu Ortop Pol 67:47–53
28. Lafontaine M, Hardy D, Delince P (1989) Stability assessment of distal radial fractures. Injury 20:208–210
29. Hargreaves DG, Drew SJ, Eckersley R (2004) Kirschner wire pin tract infection rates: a randomized controlled trial between percutaneous and buried wires. J Hand Surg Br 29:374–376
30. Knirk JL, Jupiter JB (1985) Intra-articular fractures of the distal end of the radius in young adults. J Bone Joint Surg Am 68:647–659

5 Complex Fractures of the Pelvic Ring

Juan Carlos Rubio-Suárez

5.1 Introduction

Pelvic ring fractures are not frequent, with a reported incidence of 2–8 % of all fractures [1–3]. In multiple-trauma patients, however, the frequency of pelvic ring fractures rises significantly, with an incidence of around 25 % [3–5]. In young patients, pelvic ring fractures are mostly caused by high-energy trauma. When we discuss pelvic ring disruptions, we usually refer to high-velocity accidents, such as motor vehicle and motor car crashes, falls from a great height and crush injuries. Thanks to preventive measures on the road and at workplaces, intensive controls of driver behaviour and severe punishment of violation of traffic regulations, the number of highly unstable pelvic ring lesions is slowly diminishing in industrialised countries [6].

At the same time and related to growing life expectancy, the number of ageing persons is steadily growing. As a consequence, we experience a sharp increase in the number of fractures of the proximal femur, proximal humerus, distal radius and vertebral body due to low-energy injuries. Similarly, the number of fragility fractures of the pelvic ring is increasing. Pelvic injuries in the elderly are often caused also by low-energy trauma [7, 8].

The pelvic ring provides a stable osteoligamentous compartment for the neurovascular and visceral structures of the pelvis. In accordance, disruption of the pelvic ring places patients at a high risk for severe haemorrhage and other life-threatening complications [3, 9, 10].

In a substantial number of cases, reduction of blood loss and physiological haemostasis can be achieved by rapid mechanical stabilisation of the pelvic ring [10]. Tools for emergency stabilisation of the pelvis include folded bed sheets anchored anteriorly by towel clips [11, 12], commercially available pelvic binders [13] and pelvic C-clamps [14–17]. These devices enable compression of the disrupted hemipelvis medially and does not rely on an intact posterior pelvic ring [8, 11–13, 18]. Circumferential sheets and binders realise compression of the pelvic ring indirectly via the greater trochanter, while C-clamps compress directly on the bony structures of the posterior pelvis. In contrast, external fixators function by internally rotating an externally rotated pelvis (open book fracture) but only if the posterior ring has no vertical instability [8, 19]. In vertically unstable type C fractures, an internal rotation of the pelvis by an external fixator may result in further dislocation of the posterior ring, if the posterior pelvis is not fixed as well. Sheet slings and pelvic binders can be used also in prehospital course, while the pelvic C-clamp usually has to be applied by a surgeon in a resuscitation area or

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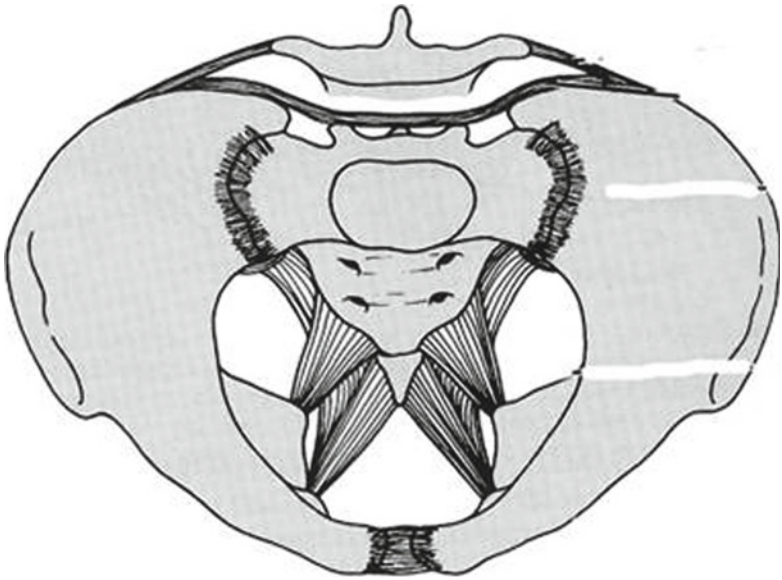

Fig. 5.1 Drawing showing the pelvic ligaments

operating room [8, 11–14]. If haemodynamic stabilisation is achieved, time for further diagnostics is attained [20]. If no haemodynamic stabilisation can be reached by mechanical stabilisation of the pelvic ring, further measures like pelvic packing or arterial embolisation are necessary [10, 21–23].

5.2 Anatomy

Pelvic ring is a bony structure made up of three bones: sacrum and two innominate bones. The innominate bone is formed from the fusion of three ossification centres: ilium, ischium and pubis. These three centres bind at the acetabulum by triradiate cartilage. Both innominate bones are joined anteriorly to one another at the pubic symphysis. Posteriorly, the innominate bone is joined the sacrum at the two sacroiliac joints. Three bones and three joints together form the pelvic ring.

Pelvic ring stability is given by strong ligamentous structures. We can divide the pelvic ligaments in two groups:

- Articular ligaments
  - Posterior sacroiliac ligaments: they are the strongest and provide major structural integrity to the sacroiliac joint.
  - Anterior sacroiliac ligament: They provides some stability but less than that provided by the posterior ligaments.
  - Symphysis ligaments: they are formed by a thick band of fibrous tissue. The thickest portion is usually superior and anterior. Inferiorly, they are reinforced by muscle insertions and the arcuate ligament.
- Extra-articular ligaments
  - Sacrotuberous ligament: it is a strong band running from the posterolateral aspect of the sacrum to the ischial tuberosity.
  - Sacrospinous ligament: it is a triangular band that runs from the lateral edge of the sacrum to the ischial spine.
  - Lumbosacral ligaments: several ligaments run from the spine to the pelvis. They originate from the transverse process of L4 and L5 and insert on the superior edge of the sacral wing and the posterior iliac crest. Figure 5.1 shows pelvic ligaments.

Inside, the pelvic ring harbours and protects a significant number of vascular, nervous, genitourinary, digestive and muscular structures that can be injured by trauma that produces the same pelvic fracture. Understanding pelvic anatomy will help us to understand and suspect retroperitoneal bleeding and recognise injuries involving genitourinary or gastrointestinal systems.

Fig. 5.2 Anteroposterior (AP) radiographic view of the pelvis

5.3 Assessment and Diagnosis

Pelvic fracture should be considered a sign leading to other associated injuries that may be life threatening. These include head, chest and abdominal injuries and, overall, retroperitoneal bleeding due to vascular injury.

5.3.1 History

The injury mechanism is the key to determine the classification and treatment setting of the fracture. It is important to know the position of the victim and the direction and intensity of the force during the impact.

5.3.2 Physical Examination

Pelvic examination includes palpation of anterior superior iliac spine and iliac crests to check position and stability and inspection of the skin, including the perineum, observing the presence of wounds, lacerations or urethral, vaginal or rectal bleeding. Do not finalise the exploration without performing a rectal and vaginal exploration.

5.3.3 Radiological Examination

A radiographic assessment of the pelvis includes an AP view (Fig. 5.2). In order to determine displacement appropriately is mandatory to obtain two more views proposed by Pennal and Sutherland in 1961 [24, 25]. However, nowadays, any traumatic injury of the pelvis, especially high energy, should be studied by computer tomography (Figs. 5.3 and 5.4). CT scan allows us to study the injury in three dimensions and establish a correct classification and appropriate treatment plan. In patients with hypovolaemic shock, the use of radiopaque contrast allows us to identify areas of bleeding.

5.4 Classification

Several classifications have been done on an anatomical basis. Judet and Letournel classification [26], based on the site of injury, is an example.

5.4.1 Young-Burgess Classification

Currently, Young and Burgess classification [27] based on mechanism of injury is widely used.

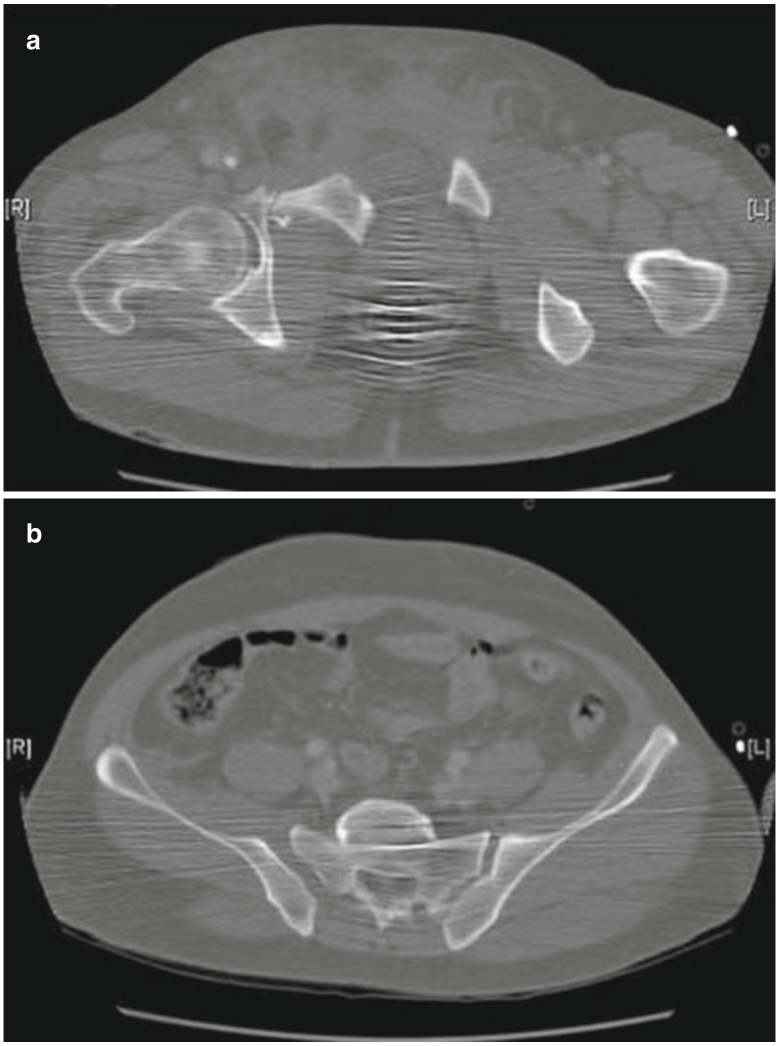

Fig. 5.3 CT (computed tomography) scan of the pelvic ring (**a**). Sagittal tomography of the same pelvis (**b**)

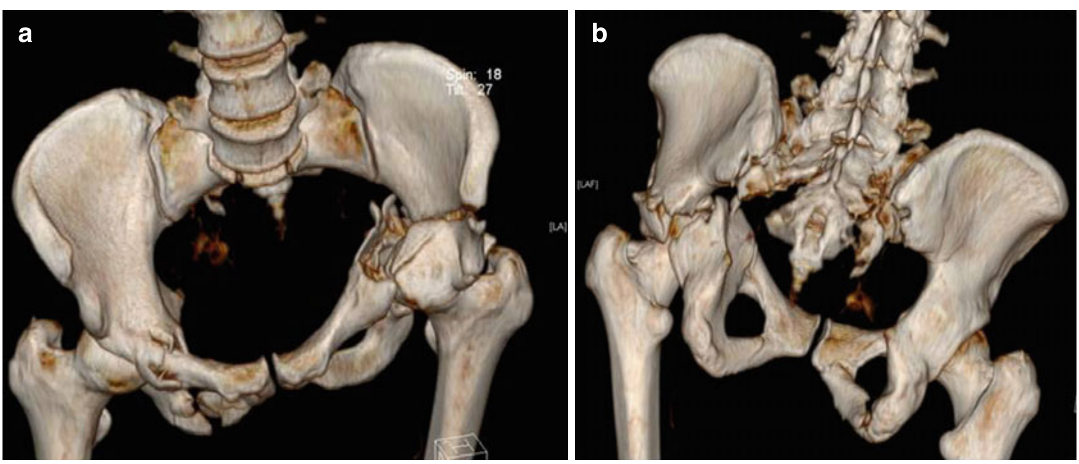

Fig. 5.4 Pelvic CT scan (**a**) and 3D reconstruction of the same pelvis (**b**)

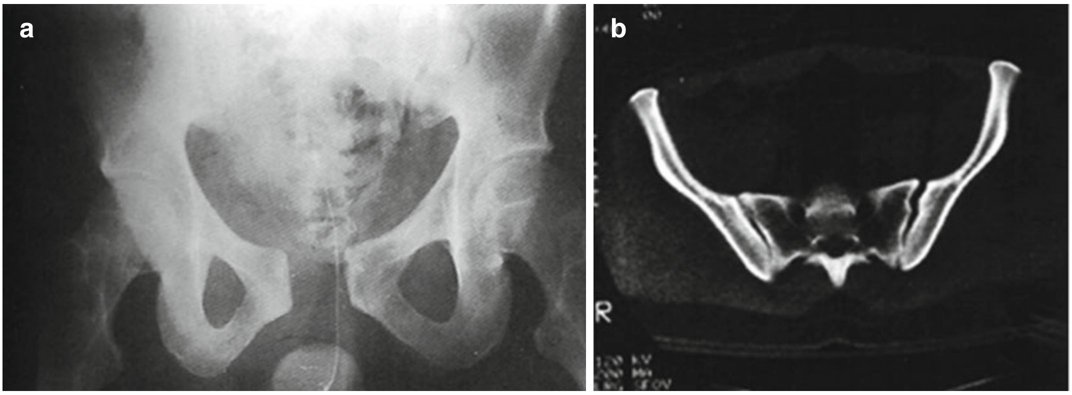

Fig. 5.5 Anteroposterior compression (APC) type II pelvic fracture. AP radiographic view (**a**) and CT scan (**b**)

Fig. 5.6 Lateral compression (LC) type II fracture: anteroposterior (AP) radiographic view

This classification takes into account the forces direction and distinguishes three components: anteroposterior compression (APC), lateral compression (LC) and vertical shearing (VS). Each group is divided into three types according to the degree of injury:

- APC fractures
  - I. Pubic diastasis <2.5 cm. No posterior component.
  - II. Pubic diastasis >2.5 cm. Anterior SI ligaments disrupted.
  - III. Pubic diastasis >2.5 cm. Anterior and posterior SI ligaments and sacrotuberal and sacrospinal ligaments disrupted. Figure 5.5 shows APC II pelvic fracture.
- LC fractures
  - I. Pubic rami fracture unilateral (ipsi- or contralateral). Impacted fracture of the sacral wing ipsilateral.
  - II. Pubic rami fracture unilateral. Posterior iliac wing fracture near to the sacroiliac (SI) joint (crescent fracture).
  - III. The same injury as type I or II associated with open book injury of the contralateral hemipelvis. Figures 5.6 and 5.7 show LC II fractures.
- VS fractures. Anterior component: pubic disruption or pubic rami fracture. Posterior component: Sacroiliac joint disruption or vertical sacral wing fracture or vertical posterior iliac wing fracture,

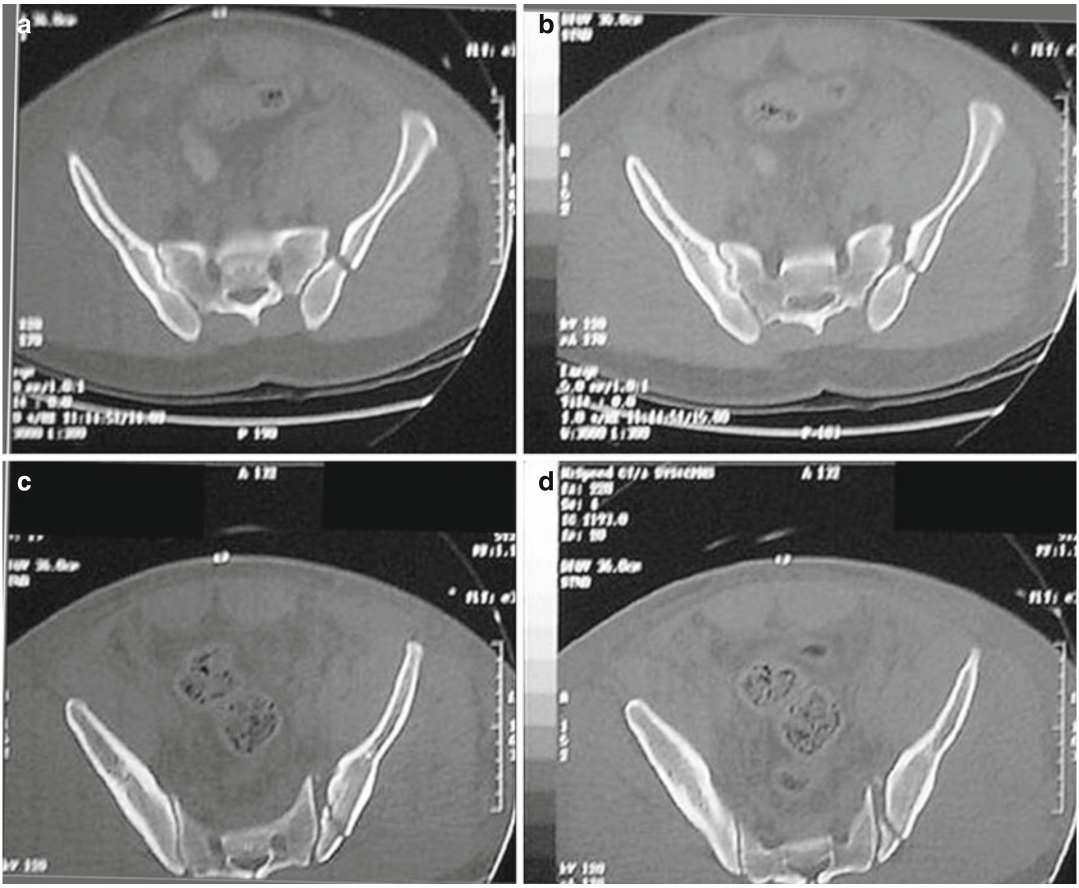

Fig. 5.7 Lateral compression (LC) II fracture: four (**a**–**d**) different CT scan images of the fracture

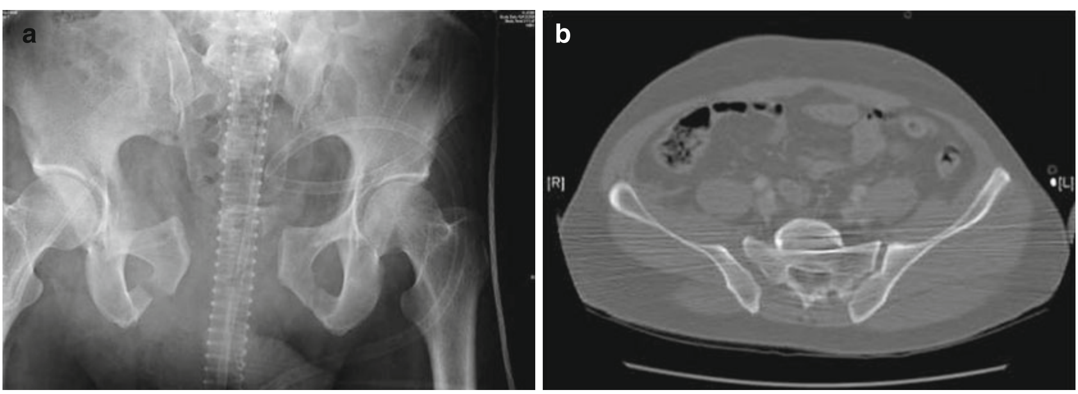

Fig. 5.8 Vertical shearing (VS) pelvic fracture: anteroposterior (AP) radiographic view (**a**) and CT scan (**b**)

complete breakdown of extra-articular ligaments (sacrotuberal and sacrospinal and lumbosacral), vertical displacement of the injured hemipelvis. Figure 5.8 shows a VS pelvic fracture.

5.4.2 Tile's Classification

The AO/OTA classification [28] combines both mechanism of injury and stability and aids in determining prognosis and treatment options. This classification is widely used today:

- Type A: stable fractures
  - A1. Avulsion of the anterior superior iliac spine, anterior inferior iliac spine or ischial tuberosity
  - A2. Unilateral pubic rami fractures
  - A3. Transverse fractures of the sacrum
- Type B: rotationally unstable
  - B1. Unilateral external rotation
  - B2. Internal rotation: lateral compression mechanism
  - B3. Bilateral external rotation: open book fractures
- Type C: rotationally and vertically unstable
  - C1. Unilateral injury
  - C2. Bilateral injury: one side rotationally unstable, other side vertically unstable
  - C3. Bilateral injury: both sides completely unstable

Analysis of the classification produced 54.8 % stable type A fractures, 24.7 % rotationally unstable type B fractures and 20.5 % type C fractures unstable in translation and concomitant acetabular fractures in 15.7 % of cases. Of the 54.8 % type A fractures, 91.1 % affected the anterior pelvic ring or were fractures of the iliac rim. Coccygeal or sacral fractures below the linea terminalis occurred in 8 % of cases. Avulsion fractures of muscle attachments were present in only 0.9 %. 10.2 % of patients in this group suffered concomitant acetabular fractures. In the case of rotationally unstable type B fractures, lateral compression was present in 57.5 % and open book fractures in 36.8 %. In 5.7 %, there was bilateral rotational instability of the posterior pelvic ring. In this group, 20.6 % had concomitant acetabular fractures. Of the 20.5 % type C fractures, 8.3 % were bilateral and 23.8 % had a concomitant acetabular fracture [29].

5.5 Treatment

We can distinguish two phases in the treatment of pelvic fractures: an initial, immediate and another delayed over the course of the following days.

5.5.1 Initial Management

5.5.1.1 Outpatient Management

Immediate stabilisation of the pelvis by a sheet or strip is a noninvasive technique, fast and secure for mobilising the patient safely. It is a mechanical procedure contained in ATLS protocols. The pelvic belt should be maintained during transport, resuscitation and diagnostic tests. Only withdraw when you know the extent of injuries, or it may be replaced by other means of stabilisation. It should not be kept more than 48 h.

5.5.1.2 External Fixation

It was described by Slatis in 1975 and today still has a major role in the emergency treatment of unstable pelvic fractures. External fixation has a dual role: to stabilise the fracture and reduce venous bleeding by reducing pelvic volume. Main indications include:

- Damage control in patients with unstable pelvic fractures and haemodynamic instability
- Unstable pelvic fractures with abdominal injuries requiring laparotomy
- Open pelvic fractures with contaminated perineal wounds

  External fixation may be:

- Anterior: by pins attached to an anterior external fixator that should allow to perform a laparotomy. Pins can be placed either in the iliac crest or in supra-acetabular position. The last option is more complex, requires Rx control and will be reserved for stable patients. Figure 5.9a, b shows an anterior pelvic fracture treated with external fixator.
- Posterior: the use of the C-clamp was introduced by Ganz in 1989. It was designed to achieve a stabilisation of the posterior elements of the pelvis and decrease bleeding of the presacral venous plexus. It is a quick and easy technique but has a high rate of complications such as intrapelvic penetration, medial displacement of the hemipelvis or damage or nerve damage in the sciatic notch, so its use may be dangerous. Figure 5.10 shows posterior pelvic external fixation by means of a C-clamp.

5.5.1.3 Retroperitoneal Packing

It consists in haemostasis by direct compression of the retroperitoneal venous plexus and is

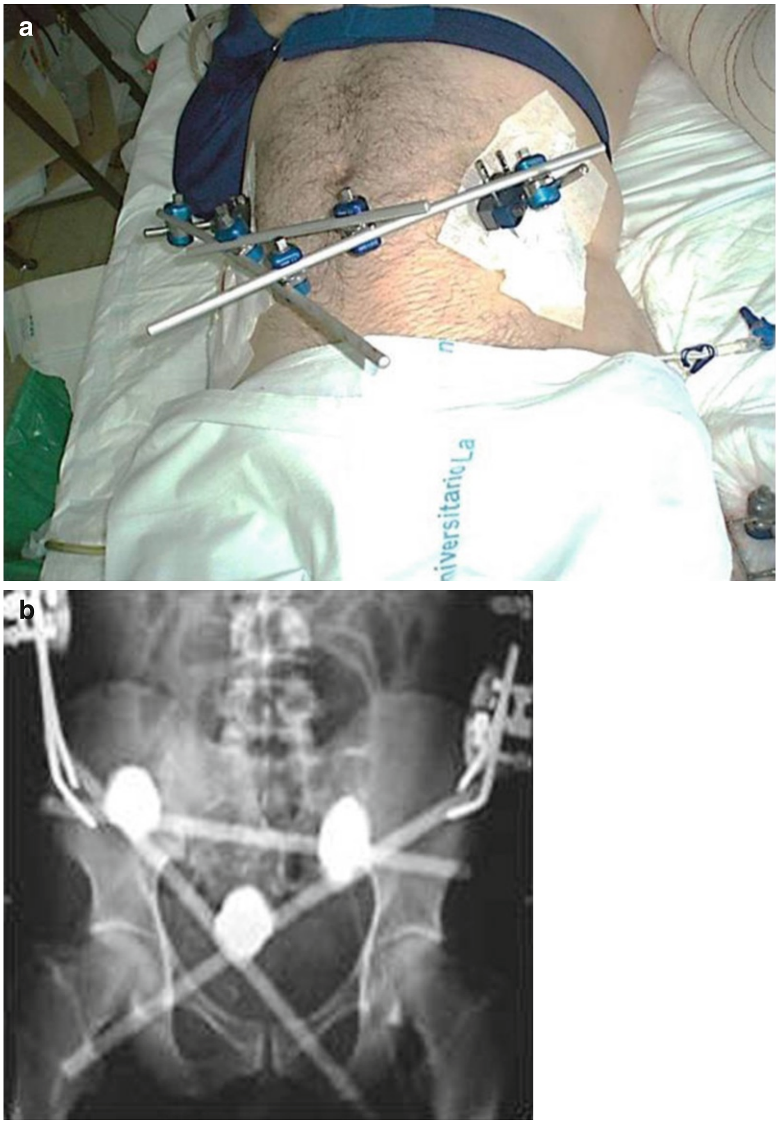

Fig. 5.9 Anterior pelvic external fixation: clinical (**a**) and radiographic image (**b**)

performed through a infraumbilical laparotomy through which wet compresses are introduced in variable number (3–15) in the retroperitoneal space. The pads will be removed within 48 h. This technique is of dubious effectiveness and is reserved for patients in extremis that cannot be taken to the angiography room.

5.5.1.4 Angiography and Embolisation

It is the treatment of choice for pelvic arterial haemorrhage. It is indicated in the absence of haemodynamic response to initial resuscitation or arterial bleeding in the angioTC. Its efficiency is 90 % when performed within 180 min after admission [30].

5.5.2 Definitive Treatment

After the patient has been monitored for immediate complications (this may take 5–10 days), we proceed to make the definitive treatment.

We choose the definitive treatment according to the fracture pattern:

- APC I: this kind of fractures does not usually need surgical management so it may be managed by symptomatic treatment.
- APC II: anterior stabilisation is enough in this kind of injuries. We use open reduction and internal fixation by plate and screws in both symphysis disruption and fractures of the

Fig. 5.10 Posterior pelvic external fixation: C-clamp

Fig. 5.11 Anterior internal fixation of pelvic ring

pubic rami. External fixation can also be used. Figure 5.11 shows anterior internal fixation of pelvic ring.

- APC III: due to the high instability, having anterior and posterior stabilisation is required. Anterior stabilisation can be obtained by external fixation or by open reduction and internal fixation with plates and screws. The injury of the back pelvic ring (sacroiliac dislocation or sacral wing fracture) can be stabilised by using percutaneous iliosacral screws under x-ray, CT scan or navigator control.
- LC I: they usually are stable injuries and so do not require surgical treatment in most cases. Symptomatic management is usually enough.
- LC II: anterior injury can be managed by external fixation or open reduction and internal fixation by plate and screws. Posterior injury (crescent fractures) requires internal fixation. We can use percutaneous screws [31] or ORIF by plate and screws onto the inner face of the iliac wing. Figure 5.12 shows anterior and posterior internal fixation of an LC II pelvic fracture.

Fig. 5.12 Anterior (symphysis plate) and posterior (percutaneous screws for crescent fracture) internal fixation of a pelvis fracture

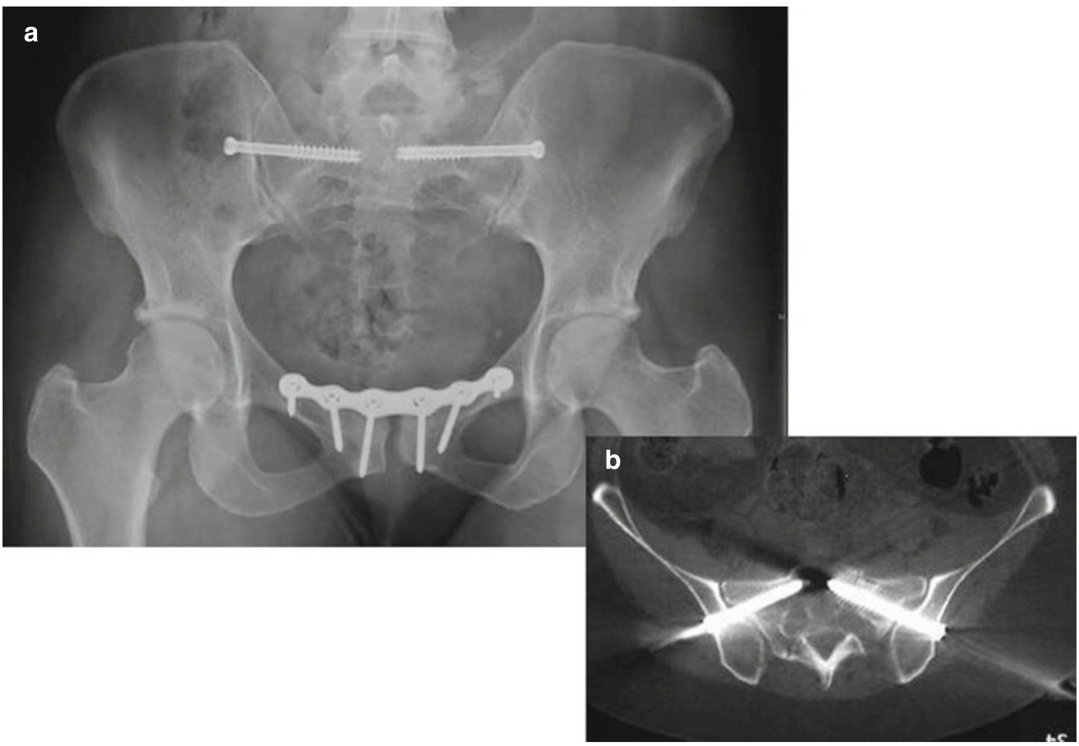

Fig. 5.13 Internal fixation of a pelvic fracture: anterior plate and bilateral percutaneous iliosacral screws. X-ray AP view (**a**) and sagittal view CT scan (**b**)

- LC III: anterior ring injury will be treated by external fixation or ORIF as mentioned for LC II. The back ring of the same side of the trauma can also be treated as mentioned for LC II. The back ring of the opposite side of the trauma (similar to an open book injury) must be treated by iliosacral percutaneous screws.

- VS: this kind of injury requires reduction by traction and then anterior stabilisation by external fixation or ORIF for the pubic component. Back ring injury can be stabilised by iliosacral percutaneous screws. Figure 5.13 shows anterior and posterior internal fixation of the pelvis.

5.6 Open Fractures

Open pelvic fractures are not frequent and account for only 2–4 % of all pelvic fractures [32, 33]. Such injuries usually result from high-energy trauma. They are present when there is a direct communication between a skin, rectal or vaginal wound and the fracture, including everything from an iliac wing fracture with a small puncture wound up to pelvic disruptions with gross external bleeding and massive displacements. In the 1980s, mortality rate was more than 50 %. Fortunately, the application of multidisciplinary protocols, with early, aggressive fracture management and selective faecal diversion, as well as advances made in modern critical care medicine, has led to reduced mortality rates from open pelvic fractures [33]. Some authors have described mortality rates as low as 5 % [32, 34]. This has been attributed to the lower incidence of associated injuries to the head and thorax, compared to previous reports [32].

5.6.1 Initial Treatment

5.6.1.1 Haemodynamic Stabilisation

Open fractures of the pelvis have more risk of bleeding than closed fractures. So haemodynamic stabilisation plays an important role in their management. Volume contribution by isotonic fluids and blood transfusion should be the first step. Then, pelvic ring stabilisation followed arterial embolisation if necessary will be done.

5.6.1.2 Pelvic Ring Stabilisation by External Fixation

Such as we do in other open fractures, open pelvic fractures must be managed according to the damage control principle. This includes stabilisation by external fixation.

5.6.1.3 Wide Wound Debridement

It includes extensive irrigation and debridement of traumatised and devitalised soft tissues, as well as the complete and radical removal of all foreign material [35–37]. At all times, early detection, together with aggressive treatment, of possible pelvic compartment syndromes is necessary. In the pelvic region, the three major compartments under consideration are the gluteus medius/minimus, the gluteus maximus and the iliopsoas compartment [38].

5.6.1.4 Early Diverting Colostomy, or Ileostomy, and Distal Rectal Washout of Residual Faeces

Penile catheterisation should only be performed once urethral integrity has been demonstrated by open retrograde cystourethrogram, thus minimising the risk of completing a partial urethral tear or creating a false tract [39, 40]. If retrograde cystourethrogram is positive for a urethral injury, a suprapubic cystostomy tube needs to be inserted during the emergency operation, to ensure diversion of the urinary flow, in order to prevent sepsis from infected urine [41, 42].

5.6.2 Definitive Treatment

5.6.2.1 Definitive Pelvic Fracture Stabilisation

Factors affecting the decision-making process are the condition of the soft tissues and the physiological status of the patient. The definitive stabilisation of open pelvic fractures remains to some extent controversial, since there is no clinical study available comparing complications and mortality for different techniques. In any case, external fixation seems to be the most safety option in most cases.

5.6.2.2 Skin and Soft Tissue Coverage

In perineal and ischial wounds associated with open pelvic fractures, local soft tissue transfer can be difficult, due to the functional necessity of neighbouring muscle groups. Free tissue transfer techniques exist to address complex wounds of the pelvis in which local donor sources are inadequate.

5.6.2.3 Urethral Realignment and Reconstructive Urethral Repair

Delayed end-to-end repair of the urethra is generally undertaken 3 months following trauma and once the acute problems, such as local infections, have resolved.

5.6.2.4 Colostomy Takedown

Traditionally, 6 weeks to 3 months following the injury colostomy takedown, with restoration of gastrointestinal tract continuity, has been advocated [43].

5.7 Complications

5.7.1 Early Complications

Immediate complications of open fractures of the pelvis are infections (sepsis, pelvic abscess, osteomyelitis, perineal wound infections) and rectal incontinence [44], with some of them being very rare, such as a septic arthritis of a hip joint following a rectal tear associated with a pelvic fracture [33].

Even in the event that an individual is able to survive the initial trauma, severe complications may further increase the cumulative risk of mortality or compromise final outcome and quality of life [45].

5.7.1.1 Infection

Low-grade infection can occur around the pin tracts of an external fixator. It usually responds well to the daily cleaning of the pins and antibiotic drugs and disappears when the pins are removed. Deep infection is rare. However, its incidence in open fractures, especially when rectal or vaginal tear exists, rises considerably.

5.7.1.2 Deep Venous Thrombosis

It has an incidence of 35 % due to lesion of the pelvic venous plexus and immobilisation. The best treatment is its prevention by administering low-molecular-weight heparin subcutaneously. This does not significantly increase the risk of bleeding [46].

5.7.2 Late Complications

5.7.2.1 Malunion

It commonly follows unreduced pelvic fractures. Symptoms are pain, deformity, leg length discrepancies and gait abnormalities. If these symptoms are severe, surgical treatment is indicated. Pelvic osteotomy of the malunion site is required.

5.7.2.2 Nonunion

It is uncommon and is more common in vertically unstable fractures. Pain and instability are the symptoms. The treatment consists in open reduction, internal stable fixation and bone grafting.

5.7.2.3 Pain

It may be due to malunion, nonunion or sacroiliac osteoarthritis. However, most patients have a chronic sacroiliac pain despite anatomical reduction and good consolidation of the fracture.

5.7.2.4 Neurologic Injuries

Nerve damage is common following pelvic fracture, with an incidence of about 10–15 % [47]. In bilateral VS fractures, the incidence rises 46 %. It may be due to traction or avulsion of sacral nerve roots, so a good reduction and stabilisation of the injury may reduce the incidence. In chronic cases, nerve roots decompression may be indicated. Lumbar sympathetic blocks may be useful in cases of chronic causalgia.

Long-term sequelae of open pelvic fractures include chronic pain, residual disability in physical functioning, incontinence, impotence and dyspareunia.

Conclusions

Pelvic ring fractures are not frequent among the general population. But their incidence increased in cases of multiple-injured patients. Because the large number of blood vessels containing it is not difficult imagine that these fractures are associated with significant bleeding that may compromise the patient's life. Very high-energy injuries can cause open fractures with vaginal or rectal tears. This situation worsens prognosis and increases the risk of infection.

Pelvic fractures that do not produce ring instability may be managed by conservative means. However, fractures affecting the ring stability should be treated by surgical stabilisation. Pelvic stabilisation may be done by external fixation as damage control surgery followed by ORIF as soon as possible. In stable patients with no other injuries, immediate ORIF may be done. Open pelvic fractures require special care. They must be managed by external fixation and treatment of the haemodynamic instability, followed by control of wounds, visceral tears and urologic injuries.

Complications of the pelvic ring fractures are frequent. Infection is rare in closed fractures, but it is frequent in open fractures. However, vein thrombosis in the lower limbs has a high incidence in both. Late complications include chronic pain, residual disability in physical functioning, incontinence, impotence and dyspareunia.

References

1. Balogh Z, King KL, Mackay P et al (2007) The epidemiology of pelvic ring fractures: a population-based study. J Trauma 63:1066–1073
2. Court-Brown CM, Caesar B (2006) Epidemiology of adult fractures: a review. Injury 37:691–697
3. Pohlemann T, Tscherne H, Baumgartel F et al (1996) Pelvic fractures: epidemiology, therapy and long-term outcome. Overview of multicenter study of the pelvis study group. Unfallchirurg 99:160–167
4. Giannoudis PV, Grotz MR, Tzioupis C et al (2007) Prevalence of pelvic fractures, associated injuries, and mortality: the United Kingdom perspective. J Trauma 63:875–883
5. Ragnarsson B, Jacobsson B (1992) Epidemiology of pelvic fractures in a Swedish county. Acta Orthop Scand 63:297–300
6. Pizanis A, Pohlemann T, Burkhardt M et al (2013) Emergency stabilization of the pelvic ring. Clinical comparison between three different techniques. Injury 44(12):1760–1764
7. Fuchs T, Rottbeck U, Hofbauer V et al (2011) Pelvic ring fractures in the elderly, Underestimated osteoporotic fracture. Unfallchirurg 114:663–670
8. Rommens PM, Hofmann A (2013) Comprehensive classification of fragility fractures of the pelvic ring: recommendations for surgical treatment. Injury 44:1733–1744
9. Durkin A, Sagi HC, Durham R, Flint L (2006) Contemporary management of pelvic fractures. Am J Surg 192:211–223
10. Holstein JH, Culemann U, Pohlemann T (2012) What are predictors of mortality in patients with pelvic fractures? Clin Orthop Relat Res 470:2090–2097
11. Routt ML Jr, Falicov A, Woodhouse E, Schildhauer TA (2002) Circumferential pelvic antishock sheeting: a temporary resuscitation aid. J Orthop Trauma 16:45–48
12. Warme WJ, Todd MS (2002) The circumferential antishock sheet. Mil Med 167:438–441
13. Jowett AJ, Bowyer GW (2007) Pressure characteristics of pelvic binders. Injury 38:118–121
14. Ganz R, Krushell RJ, Jakob RP, Kuffer J (1991) The antishock pelvic clamp. Clin Orthop Relat Res 267:71–78
15. Tiemann AH, Bohme J, Josten C (2006) Use of the pelvic clamp in polytraumatised patients with unstable disruption of the posterior pelvic ring. Modified technique–risks–problems. Orthopade 35:1225–1236
16. Heini PF, Witt J, Ganz R (1996) The pelvic C-clamp for the emergency treatment of unstable pelvic ring injuries. A report on clinical experience of 30 cases. Injury 27(Suppl 1):S-A38–S-A45
17. Rommens PM, Hofmann A, Hessmann MH (2010) Management of acute hemorrhage in pelvic trauma: an overview. Eur J Trauma Emerg Surg 36:91–99
18. Biffl WL, Smith WR, Moore EE et al (2001) Evolution of a multidisciplinary clinical pathway for the management of unstable patients with pelvic fractures. Ann Surg 233:843–850
19. Slatis P, Karaharju EO (1975) External fixation of the pelvic girdle with a trapezoid compression frame. Injury 7:53–56
20. Pohlemann T, Culemann U, Gansslen A, Tscherne H (1996) Severe pelvic injury with pelvic mass hemorrhage: determining severity of hemorrhage and clinical experience with emergency stabilization. Unfallchirurg 99:734–743
21. Culemann U, Tosounidis G, Reilmann H, Pohlemann T (2004) Injury to the pelvic ring. Diagnosis and current possibilities for treatment. Unfallchirurg 107:1169–1181
22. Totterman A, Madsen JE, Skaga NO, Roise O (2007) Extraperitoneal pelvic packing: a salvage procedure to control massive traumatic pelvic hemorrhage. J Trauma 62:843–852
23. Cothren CC, Osborn PM, Moore EE et al (2007) Preperitonal pelvic packing for hemodynamically unstable pelvic fractures: a paradigm shift. J Trauma 62:834–839
24. Edeiken-Monroe BS, Savolaine ER, Jackson R (1989) The role of standard roentgenograms in the evaluation of instability of pelvic ring disruption. Clin Orthop Relat Res 240:63–76
25. Pennal GF, Sutherland GO (1961) Fractures of the pelvis. Motion picture. American Academy of Orthopedic Surgeons Film Library

26. Letournel E (1980) Acetabular fractures: classification and management. Clin Orthop Relat Res 151: 81–106
27. Young JWR, Burguess AR (1987) Radiological management of pelvic ring fractures. Urban and Schwarzenberg, Baltimore, p 22
28. Tile M (1988) Pelvic ring fractures: should they be fixed? J Bone Joint Surg 70B:1–12
29. Gänsslen A, Pohlemann T, Paul C, Lobenhoffer P (1996) Epidemiology of pelvic ring injuries. Injury 27(Suppl 1):13–20
30. El-Haj M, Bloom A, Mosheiff R et al (2013) Outcome of angiographic embolisation for unstable pelvic ring injuries: factors predicting success. Injury 44:1750–1755
31. Calafi LA, Routt ML Jr (2013) Posterior iliac crescent fracture-dislocation: what morphological variations are amenable to iliosacral screw fixation? Injury 44:194–198
32. Ferrera PC, Hill DA (1999) Good outcomes of open pelvic fractures. Injury 30:187–190
33. Brenneman FD, Kaytal D, Boulanger BR et al (1997) Long term outcome in open pelvic fractures. J Trauma 42:773–777
34. Grotz MRW, Allami MK, Harwood P et al (2005) Open pelvic fractures: epidemiology, current concepts of management and outcome. Injury 36:1–13
35. Richardson JD, Harty J, Amin M, Flint LM (1982) Open pelvic fractures. J Trauma 22:533–537
36. Birolini D, Steinman E, Utiyama EM, Arroyo AA (1990) Open pelviperineal trauma. J Trauma 30:492–495
37. Pell M, Flynn WJ, Seibel RW (1998) Is colostomy always necessary in the treatment of open pelvic fractures? J Trauma 45:371–373
38. Routt ML, Nork SE, Mills WJ (2002) High-energy pelvic ring disruptions. Orthop Clin North Am 33:59–72
39. Govaert G, Siriwardhane M, Hatzifotis M (2012) Prevention of pelvic sepsis in major open pelviperineal injury. Injury 43:533–536
40. Routt ML, Nork SE, Mills WJ (2002) High-energy pelvic ring disruptions. Orthop Clin North Am 33:59–72
41. Sharlip ID (1981) Penile arteriography in impotence after pelvic trauma. J Urol 126:477–481
42. David A, Mollenhoff G, Josten C, Muhr G (1996) Perineal injuries in complicated pelvic trauma. Swiss Surg 1:4–9
43. Koraitim MM (1999) Pelvic fracture urethral injuries: the unresolved controversy. J Urol 161:1433–1441
44. Fallon WF Jr (1992) The present role of colostomy in the management of trauma. Dis Colon Rectum 35:1094–1102
45. Arroyo W, Nelson KJ, Belmont PJ Jr et al (2013) Pelvic trauma: what are the predictors of mortality and cardiac venous thrombo-embolic and infectious complications following injury? Injury 44:1745–1749
46. Geers WH, Jay R, Code KI et al (1996) A comparison of low dose heparin with low-molecular-weight as prophylaxis against venous thromboembolism after major trauma. N Engl J Med 335:701–707
47. Weis EB (1984) Subtle neurological injuries in pelvic fractures. J Trauma 24:983–985

6 Complex Fractures of the Acetabulum

Eduardo Zamora-Carrera
and Juan Carlos Rubio-Suárez

6.1 Introduction

The treatment of acetabular fractures is a complex area of orthopaedics that is continually refined. Until the middle of the twentieth century, surgical treatment of pelvic and acetabular fractures was non-existent [1].

In the early 1960s, the management of acetabular fractures was revolutionised by the work of Judet and Letournel. They recognised that the principles applied to the treatment of displaced articular fractures (anatomic reduction, stable fixation, and early movement) should also be applied to the acetabulum. Their studies led them develop news surgical approaches and a classification system which has been tested in time and is currently used all over the world [2]. This approach led to a reduction in the incidence of post-traumatic arthritis and an improvement in the overall outcome.

Acetabular fractures constitute 18 % of pelvic injuries and most often occur in young adults involved in high-energy motor vehicle collisions or falls from a height. As with pelvic fractures, acetabular fractures also can occur in older patients with osteoporotic bone, usually from a low-energy fall.

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6.2 Anatomy

The acetabulum can be described as an incomplete hemispherical socket with an inverted horseshoe-shaped articular surface surrounding the nonarticular cotyloid fossa. This articular socket is composed of and supported by two columns of bone, described by Letournel and Judet as an inverted Y [3].

The anterior column is defined as the strut of bone that extends from the sacroiliac joint to the ipsilateral pubic ramus. The anterior column includes the superior pubic ramus, anterior half of the acetabulum, anterosuperior and anteroinferior iliac spines, and anterior iliac crest. The iliopectineal (also called the iliopubic) line on radiographs approximates the anatomic anterior column [4].

The posterior column is the bony strut extending from the posterosuperior iliac spine to the ischial tuberosity. The posterior column includes the portion of the ischium from the ischiopubic junction of the obturator foramen to the greater sciatic notch and posterior half of the acetabulum. The ilioischial line on radiography approximates the anatomic posterior column.

The walls of the acetabulum extend from the corresponding columns, consequently forming the acetabular cup, and stabilise the hip joint. The posterior wall is larger and extends more laterally; the anterior wall is smaller and stabilises the hip joint anteriorly and has been described as extending to the pelvic rim [5].

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The neurovascular structures passing through the pelvis are at risk during the original injury and subsequent treatment, and the various surgical approaches are designed around these structures. The sciatic nerve exiting the greater sciatic notch inferior to the piriformis muscle frequently is injured with posterior fractures-dislocations of the hip and fractures with posterior displacement. The superior gluteal artery and nerve exit the greater sciatic notch at its most superior aspect and can be tethered to the bone at this level by variable fascial attachments.

6.3 Clinical Evaluation

Patients with acetabular fractures often have multiple injuries and the initial approach to evaluation should follow ATLS guidelines [5]. Careful assessment of the ipsilateral lower extremity should be taken and performed to rule out fracture or ligamentous injury of the knee. The soft tissues overlying the greater trochanter should be carefully inspected for signs of a Morel-Lavallee lesion, a closed degloving injury resulting in a haematoma and liquefied fat forming between the subcutaneous tissues and the fascial layer. Sciatic nerve function should be carefully assessed in the ipsilateral extremity, especially with fractures involving the posterior wall.

6.4 Radiographic Evaluation

Acetabular fracture classification by Judet and Letournel requires oblique radiographs of the pelvis. A standard radiograph series consists of an anteroposterior view and left and right Judet views. Judet views are right posterior oblique (also known as right iliac oblique or left obturator oblique) and left posterior oblique (also known as left iliac oblique or right obturator oblique) views of the pelvis. Appropriate positioning of the obliquity is confirmed by ensuring that the coccyx projects over the ipsilateral femoral head: In the right posterior oblique projection, the coccyx should project over the right femoral head.

The obturator oblique view splays open the contralateral iliac wing and allows visualisation of the ipsilateral iliopectineal line and posterior wall. For example, with a right obturator oblique view, the right iliopectineal line, left iliac wing, and right posterior wall are best visualised.

An iliac oblique view shows the ipsilateral ilioischial line and the anterior wall. Thus, the right iliac oblique view will show the entire right ilium en face, the right anterior wall, and the left posterior wall. These views are critical to orthopaedists because they are the intraoperative views used to judge reduction.

CT scan better defines acetabular fractures, particularly in identifying the location and displacement of fractures and loose fragments in the hip joint. CT also helps with preoperative planning. Furthermore, CT offers better soft tissue assessment for rapid evaluation of visceral structures in the multitrauma patient [6] (Figs. 6.1 and 6.2).

6.5 Classification

There are several acetabular fracture classification schemes, with the most widely used classification scheme being the Judet-Letournel classification scheme.

In the Judet-Letournel classification system, acetabular fractures are classified into two broad categories: elementary and associated fractures. The associated fracture patterns are composed of a combination of at least two of the elementary fracture patterns. The importance of this classification system lies in the fact that different acetabular fractures are repaired by different surgical approaches and techniques [7].

Elementary fractures include wall, column, and transverse fractures. These fracture types can easily be remembered by recalling the basic functional anatomy of the acetabulum: Elementary fractures involve a single wall, a single column, or are purely transverse. The simplest elementary fractures are two-part fractures. It is important to note that the term "transverse fracture" should be reserved to describe a diagnostic type of acetabular fracture, whereas the term "transverse" should be avoided when describing the orientation of a

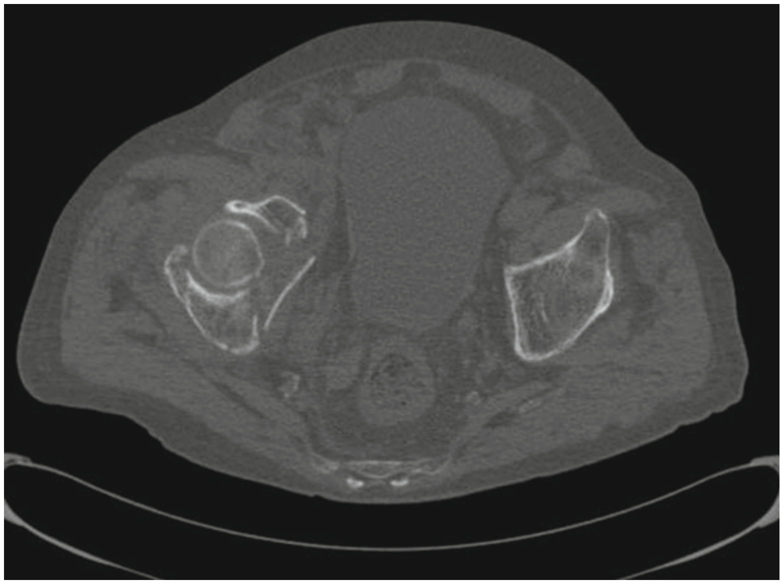

Fig. 6.1 CT scan. Axial view of acetabular fracture

Fig. 6.2 CT scan. 3D reconstruction of acetabular fracture

fracture because it may quickly become confusing as to which type of fracture is present.

Associated fracture patterns have at least three major fracture fragments and include a posterior column fracture with a posterior wall fracture, a transverse fracture with a posterior wall fracture, an anterior column fracture with a posterior hemi-transverse fracture, a T-type transverse fracture, and associated both-column fractures.

Although there are ten fracture patterns, 90 % of acetabular fractures that occur are one of five types: associated both-column, T-type, transverse, transverse with posterior wall, and elementary posterior wall fractures [8]. Some investigators have advocated concentrating only on these common fractures; however, commonly acetabular fractures do not fit perfectly in one of the fracture patterns in the classification scheme.

The most frequent type of fracture involved the posterior wall, accounting for 23.9 % of all injuries. Fractures involving both columns were seen in 22 %, those described as transverse and involving the posterior wall accounted for

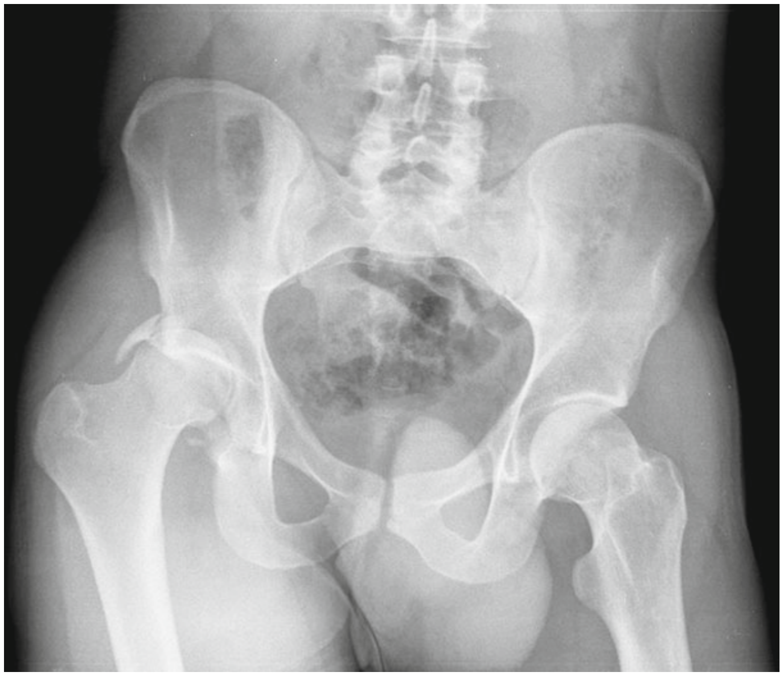

Fig. 6.3 Posterior wall fracture

17.7 %, while other fracture types were less common and were seen in less than 10 %.

The AO group has developed an alphanumeric classification system for acetabular fractures based on the severity of the fracture: Type A fractures include fractures of a single wall or column, type B fractures involve both anterior and posterior columns (both transverse or T-type fractures), and type C fractures involve both anterior and posterior columns, but all articular segments, including the roof, are detached from the remaining segment of the intact ilium. Type C fractures are those designated both-column fractures in the Letournel and Judet classification. Each type has subtypes 1, 2, and 3, depending on the characteristics of the fracture (Figs. 6.3, 6.4, and 6.5).

6.6 Treatment

6.6.1 Nonsurgical Treatment

In the past few decades, indications for conservative management have been reduced to a minimum, and it is currently used mostly in circumstances preventing surgery [9].

Nondisplaced fractures or displaced fractures that do not involve the dome of the acetabulum are treated nonsurgically. The dome of the acetabulum has been defined by Matta et al. [10] as the area within the 45° roof arc or the superior 10 mm on a CT scan. An exception to this rule is posterior wall fractures, which may not involve the dome but nevertheless can result in hip instability if a large fragment is involved.

Some both-column fractures have extensive comminution, but the fragments remain minimally displaced around the femoral head. This so-called secondary congruence also allows for nonsurgical management. Other contraindications to open reduction and internal fixation include the following: associated medical conditions that prevent surgery; advanced osteoporosis or degenerative joint disease, making hip arthroplasty the better option; and local or systemic sepsis. In all those cases, the treatment consists in mobilisation out of bed with toe-touch weight bearing for 10–12 weeks.

6.6.2 Surgical Treatment

Open reduction and internal fixation, as for any other intra-articular fracture, is now a standard treatment for a displaced acetabular fracture. In

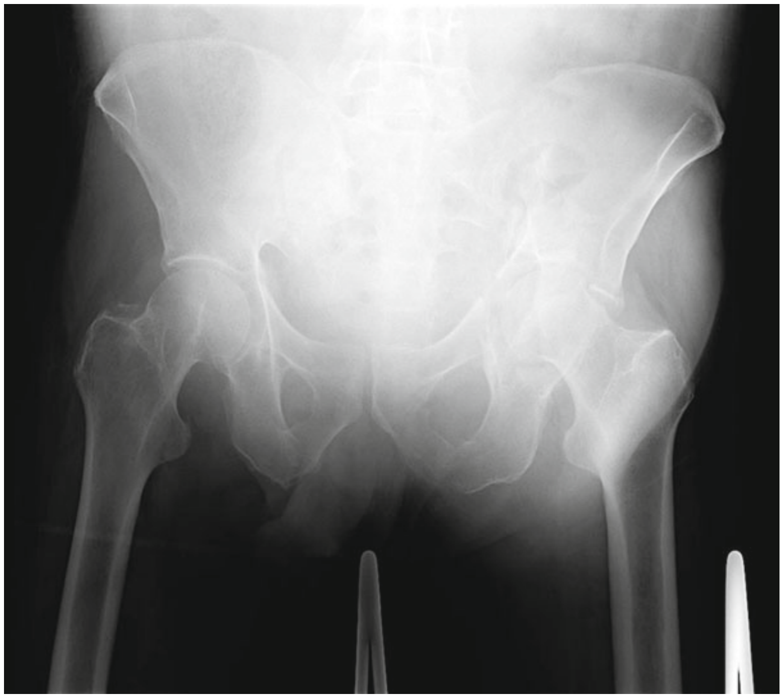

Fig. 6.4 T-shaped fracture

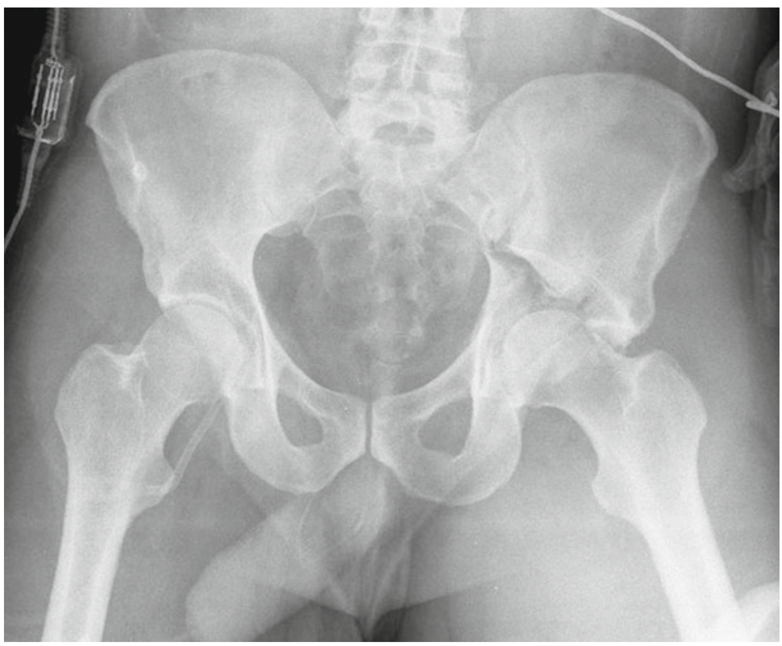

Fig. 6.5 Both-column fracture

a comparative study, nonoperative treatment of the displaced acetabular fracture has been shown to give far inferior results compared to operative treatment (30 % good results versus 86 % good results). The goal of treatment of a displaced acetabular fracture is to achieve anatomical reduction of the articular surface with rigid internal fixation to allow early joint motion, but the choice of surgical approach remains controversial [11].

6.6.2.1 Indications for Operative Treatment and Selection of Approach

Indications include fractures involving the dome of the acetabulum with at least 2 mm of displacement, fractures that result in instability of the hip joint, and fractures with trapped intra-articular fragments. The approach selected depends on pattern and location of the fracture. Fractures involving a single column or wall can be approached through a single approach (ilioinguinal or modified Stoppa for anterior fractures and Kocher-Langenbeck for posterior fractures).

The Kocher-Langenbeck approach is used most frequently in the operative treatment of acetabular fractures. It gives access to the retroacetabular surface of the innominate bone from the ischium to the greater sciatic notch. Access to the quadrilateral surface is possible by palpation through the greater and lesser sciatic notches, allowing assessment after the reduction of fractures involving the quadrilateral plate and anterior column. The greater sciatic notch also provides a window for the placement of clamps to manipulate and reduce these fractures. The superior gluteal neurovascular bundle limits access to the superior iliac wing in this approach.

The ilioinguinal approach offers a direct view of the iliac wing, the anterior sacroiliac joint, the entire anterior column, and the pubic symphysis.

Both-column fractures may require both an anterior and a posterior approach or an extensile approach such as the extended iliofemoral. This is an anatomical approach and follows an internervous plane, reflecting anteriorly the femoral nerve-innervated muscles and posteriorly the muscles innervated by the superior and inferior gluteal nerves. The posterior flap is mobilised as a unit without damaging its neurovascular bundles.

This approach provides direct exposure of the whole outer aspect of the ilium, the posterior column down to the ischium, and the hip joint. With further retraction of the iliopsoas and abdominal muscles medially, exposure of the internal aspect of the ilium is also possible.

6.6.2.2 Fracture Osteosynthesis

Posterior wall fractures are the commonest type of acetabular fracture. Fractures of the posterior wall of the acetabulum as well as fractures of the posterior column, fractures of the posterior column and wall, transverse fractures, and transverse posterior wall T-shaped fractures can be managed with the operative technique described below [12].

Displaced posterior column fractures can be reduced using either a bone hook or a reduction forceps. Rotational deformities can be corrected by inserting a Schanz screw into the ischial tuberosity, thus allowing manipulation of the deformity.

In an isolated posterior wall fracture, the fragment is reduced anatomically and held with the aid of K-wires. Lag screws can then be inserted from the wall to the posterior column. A depth gauge is usually used to determine the screw length and 3.5 mm screws are used from the posterior wall to the posterior column. The overall fixation is then neutralised by the application of 3.5 plate appropriately contoured to accommodate the shape of the posterior column. The plate must be contoured adequately to include coverage of the posterior wall fracture. Where there is a transverse facture, a screw can be inserted from the posterior to the anterior column.

Isolated anterior column and anterior wall fractures account for only 6.3 % of acetabular fractures. Their outcome is often analysed with other associated fracture patterns, particularly hemi-transverse or bicolumnar fractures, thereby masking their true prognosis. In spite of extensive literature on the management of acetabular fractures in general, information on outcome following open reduction and internal fixation (ORIF) of anterior column and anterior wall fractures is scarce [13]. Depending on the displacement and stability of the fracture fragments, either closed reduction and percutaneous fixation or ORIF through an ilioinguinal approach can be performed (Figs. 6.6, 6.7, and 6.8).

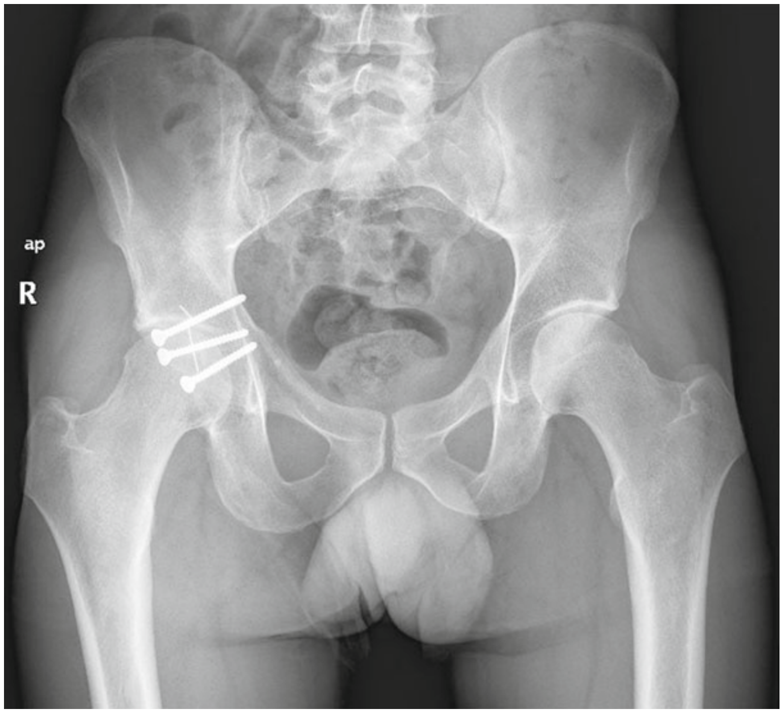

Fig. 6.6 Posterior wall osteosynthesis using screws

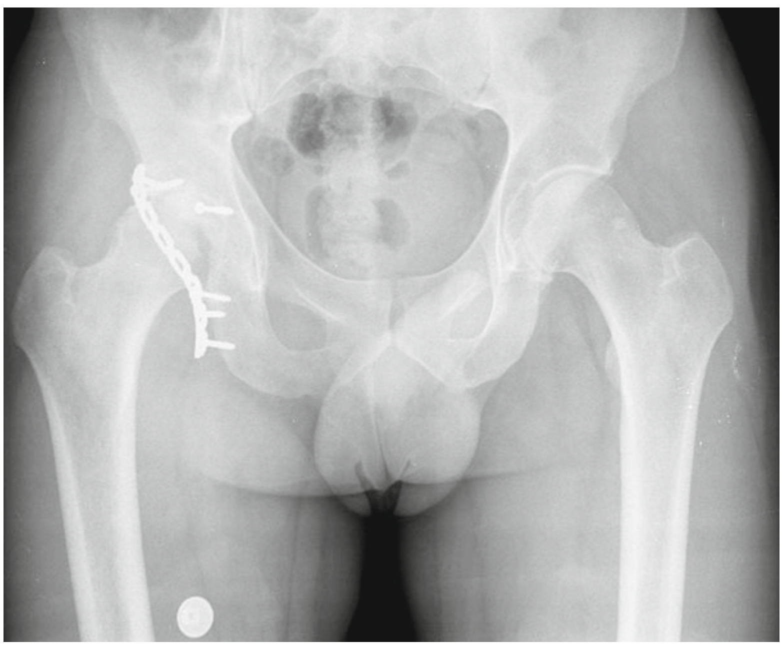

Fig. 6.7 Posterior wall osteosynthesis using plate

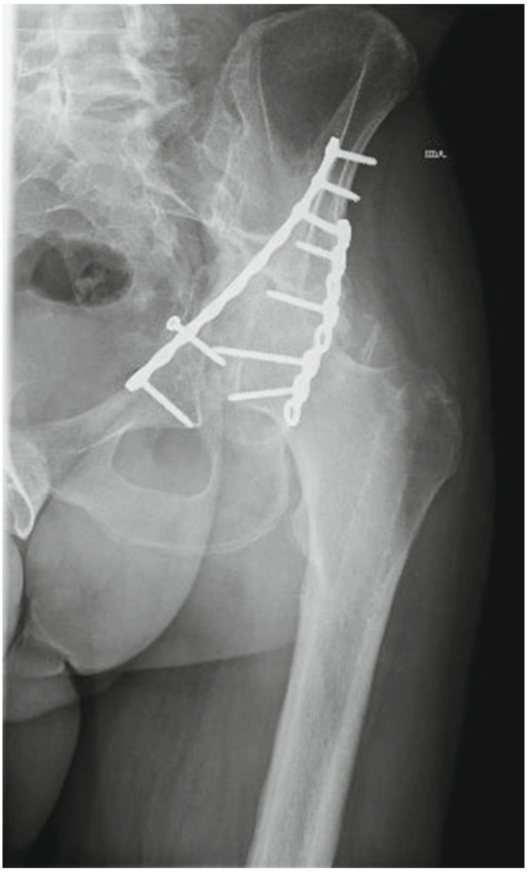

Fig. 6.8 Both-column osteosynthesis across double approach

6.7 Outcomes and Complications

Following stable fixation, patients should be mobilised as soon as possible. Weight bearing on the injured side is limited to touch down for 10–12 weeks. With stable fractures or solid fixation, active and active-assist range of motion of the affected extremity is begun as soon as symptoms allow. Isometric quadriceps exercises and straight leg raises are begun early to minimise thigh atrophy. Full weight bearing is delayed for 10–12 weeks, at which point progressive strengthening exercises are added.

The outcome following acetabular fracture may be influenced by various factors. Those beyond the surgeon's control include the mechanism of the injury, damage to the femoral head, sciatic nerve injury, dislocation, fracture pattern, associated injuries, the patient's age, and comorbidities. Crucial yet controllable factors include the timing of surgery, surgical selection, and quality of reduction and fixation. Restoration of articular congruity with stable fixation is the most significant predictive factor of post-traumatic osteoarthritis [14]. Complex associated fractures need to be fixed within the first 5 days, but more simple fractures can be adequately managed up to 15 days after the injury. Beyond this time, results become less satisfactory.

Mears et al. [15] showed in his study of 424 fractures treated by operation that simple fractures were reduced anatomically in 87 % of patients, whereas associated fractures could be reduced anatomically in only 59 %. Matta [16] had similar results, achieving anatomical reduction in 96 % of simple fractures and only 64 % of associated fractures. Both agree that both-column and T-type fractures showed the least accuracy of reduction.

6.7.1 Early Complications

Deep vein thrombosis (DVT) is a major concern for patients with acetabular fractures. Prevention includes use of pneumatic compression boots and chemical prophylaxis.

Iatrogenic nerve or vessel injury can result from surgical treatment. Maintaining the knee in flexion and the hip in extension during the Kocher-Langenbeck approach helps to decrease the tension on the sciatic nerve. Self-retaining retractors should be used with caution. There is an overall incidence of post-traumatic nerve palsies associated with acetabular fractures of 16.4 %. This rises to more than 40 % in fractures involving a posterior dislocation of the hip. The incidence of infection is between 4 and 5 %.

6.7.2 Late Complications

Heterotopic ossifications are most common with the extended iliofemoral and Kocher-Langenbeck approaches and least common with the ilioinguinal approach. A meta-analysis by Giannoudis et al. [17] showed an incidence of 25.6 % of HO following operation for acetabular fractures. However, only 5.7 % of patients will develop HO grade III or IV according to the Brooker classification. Several clinical studies have shown that either local radiation or oral administration of indometacin provided effective prophylaxis against HO following the surgical treatment of acetabular fractures.

The overall incidence of osteoarthritis (OA) following operatively treated acetabular fractures is around 26 %. Higher rates can be reached, especially in anterior column/posterior hemitransverse, T-shaped, and posterior wall/posterior column fractures. Further risk factors for the development of post-traumatic OA include associated chondral or osseous lesions of the femoral head and the quality of reduction.

The incidence of avascular necrosis (AVN) described in published papers varies from 3 to 53 %. Recent reports show that it may be grossly overestimated and that most of the observed changes in the head of the femur are probably due to OA. However, in patients sustaining a posterior fracture dislocation of the hip, the incidence of AVN increased up to 9.2 % [18].

8.5 % of patients with fractures treated by operation needed an arthroplasty at an average of 2 years following the initial procedure. Anyway, long-term results are influenced by numerous factors. The type of fracture and the quality of the reduction are the main influences on functional outcome. The quality of reduction is a crucial but controllable factor. An excellent or good functional outcome can be expected in between 83 and 89 % of patients with an anatomical reduction [19].

The treatment of these fractures sets high demands and needs to be in the hands of experts. Tertiary referrals should be undertaken as early as possible, since the timing is of utmost importance. It is important, at operation, to obtain the most accurate reduction of the fracture, which is possible, with a minimal surgical approach. Both, anatomical reduction and minimal approach, influence the outcome.

Conclusions

Acetabular fractures constitute 18 % of pelvic injuries, and most often occur in young adults involved in high-energy motor vehicle collisions or falls from a height. The treatment of acetabular fractures is a complex area of orthopaedics that is continually refined. Patients with acetabular fractures often have multiple injuries and the initial approach to evaluation should follow ATLS guidelines. CT scan is currently the best diagnosis tool in the acetabular fracture assessment. There are several acetabular fracture classification schemes. However, the most widely used is the Judet-Letournel classification scheme. Nondisplaced fractures or displaced fractures that do not involve the dome of the acetabulum are treated nonsurgically, except posterior wall fractures.

Open reduction and internal fixation, as for any other intra-articular fracture, is now a standard treatment for a displaced acetabular fracture. The approach selected depends on pattern and location of the fracture: ilioinguinal or modified Stoppa for anterior fractures and Kocher-Langenbeck for posterior fractures. Both-column fractures may require both an anterior and a posterior approach. Early complications include deep vein thrombosis, post-traumatic nerve palsies (16.4 %), and wound infection (4–5 %). Late complications are as follows: heterotopic ossification (25.6 %), osteoarthritis (26 %), and avascular necrosis (3–53 %). 8.5 % of the patients require total hip arthroplasty 2 years following the initial procedure. The treatment of these fractures sets high demands and needs to be in the hands of experts. In these cases, an excellent or good functional outcome can be expected in between 83 and 89 % of patients with an anatomical reduction.

References

1. Giannoudis PV, Bircher M, Pohlemann T (2007) Advances in pelvic and acetabular surgery. Injury 38:395–396
2. Judet R, Judet J, Leturnel E (1964) Fractures of the acetabulum. Classification and surgical approaches for open reduction. J Bone Joint Surg Am 46:1615–1636

3. Lawrence DA, Menn K, Baumgaertner M, Haims AH (2013) Acetabular fractures: anatomic and clinical considerations. AJR Am J Roentgenol 201:W425–W436
4. Lenarz CJ, Moed BR (2007) A typical anterior wall fracture of the acetabulum: case series of anterior acetabular rim fracture without involvement of the pelvic brim. J Orthop Trauma 21:515–522
5. Alonso JE, Volgas DA, Giordano V, Stannard JP (2000) A review of the treatment of hip dislocation associated with acetabular fractures. Clin Orthop Relat Res 377:32–43
6. O'Toole RV, Cox G, Shanmuganathan K et al (2010) Evaluation of computed tomography for determining the diagnosis of acetabular fractures. J Orthop Trauma 24:284–290
7. Potok PS, Hopper KD, Umlauf MJ (1995) Fractures of the acetabulum: imaging, classification, and understanding. Radiographics 15:7–23
8. Durkee NJ, Jacobson J, Jamadar D, Karunakar MA, Morag Y, Hayes C (2006) Classification of common acetabular fractures: radiographic and CT appearances. AJR Am J Roentgenol 187:915–925
9. Sen RK, Veerappa LA (2009) Long-term outcome of conservatively managed displaced acetabular fractures. J Trauma 67:155–159
10. Matta JM, Anderson LM, Epstein HC, Hendricks P (1986) Fractures of the acetabulum: a retrospective analysis. Clin Orthop Relat Res 205:230–241
11. Kumar A, Shah NA, Kershaw SA, Clayson AD (2005) Operative management of acetabular fractures. A review of 73 fractures. Injury 36:605–612
12. Giannoudis PV, Nikolaou VS (2008) Surgical techniques–How do I do it? Open reduction and internal fixation of posterior wall fractures of the acetabulum. Injury 39:1113–1118
13. Giannoudis PV, Kanakaris NK, Dimitriou R, Mallina R, Smith RM (2011) The surgical treatment of anterior column and anterior wall acetabular fractures. J Bone Joint Surg Br 93:970–974
14. Briffa N, Pearce R, Hill AM, Bircher M (2011) Outcomes of acetabular fracture fixation with ten years' follow-up. J Bone Joint Surg Br 93:229–236
15. Mears DC, Velyvis JH, Chang CP (2003) Displaced acetabular fractures managed operatively: indicators of outcome. Clin Orthop Relat Res 407:173–186
16. Matta JM (1996) Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am 78:1632–1645
17. Giannoudis PV, Grotz MRW, Papakostidis C, Dinopoulos H (2005) Operative treatment of displaced fractures of the acetabulum. A meta-analysis. J Bone Joint Surg Br 87:2–9
18. Moed BR, Willson Carr SE, Watson JT (2002) Results of operative treatment of fractures of the posterior wall of the acetabulum. J Bone Joint Surg Am 84:752–758
19. Murphy D, Kaliszer M, Rice J, McElwain JP (2003) Outcome after acetabular fracture: prognostic factors and their inter-relationships. Injury 34:512–517

7 Complex Fractures of the Distal Femur

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7.1 Introduction

Fractures of the distal femur are defined as fractures from the articular surface to 5 cm above the metaphyseal flare. The anatomical axis of the distal femur is 6–7° of valgus. The lateral cortex of the distal femur slopes about 10°, while the medial cortex slopes about 25°.

Fractures of the distal femur are often complex injuries presenting numerous potential complications. There is a bimodal distribution of fractures of the distal femur based on age and gender. Most high-energy fractures of the distal femur occur in males between 15 and 50 years, while most low-energy fractures occur in osteoporotic women >50 years [1]. The most common high-energy mechanism of injury is a traffic accident (53 %) and the most common low-energy mechanism is a fall (33 %).

Fractures of the distal femur involve the femoral condyles and the metaphysis [2]. Understanding the deforming forces involved is paramount for successful operative management. Shortening of the fracture with varus and extension of the distal articular segment is the typical deformity. Shortening is caused by the quadriceps and hamstrings. The varus and extension deformities are due to the unopposed pull of the hip adductors and gastrocnemius muscles, respectively [3].

The most common classification system used for fractures of the distal femur is the ASIF (Association for the Study of Internal Fixation)/OTA (Orthopaedic Trauma Association) system [4]. The distal femur is number 33 in this system, and the fracture is then classified based on the amount of articular involvement and comminution. Type 33-A is an extraarticular fracture. Type 33-B is a partial articular fracture involving one of the femoral condyles. Type 33-C is a complete articular fracture. Each of the letter designations is further classified into 1, 2, or 3 based on the amount and location of comminution.

ASIF/OTA 33-C3 distal femur fracture is characterized by complex articular involvement and is often accompanied by a very short distal femur segment, small osteochondral fragments, and high-energy soft tissue injury. Current fixation strategies try to provide optimal reduction of the articular surface in conjunction with stable fixation of the distal femoral segment. In the treatment of the 33-C3 distal femur fractures malunion, loss of fixation, need for supplemental fixation, and need for bone grafting (autogenous bone graft) are common.

On physical examination vascular assessment is paramount due to the potential for injury to the popliteal artery if significant displacement is present. If no pulse after gross alignment is restored, then angiography must be indicated.

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The surgical management of complex fractures of the distal femur must be based on classification, patient selection, and preoperative planning. The complex nature of combined fractures and soft tissue injuries of the distal femur needs special attention and specific management.

7.2 Imaging

Adequate radiographic evaluation of fractures of the distal femur includes standard anteroposterior and lateral radiographs of the entire length of the femur to avoid missing ipsilateral femoral neck or shaft fractures. Knee (anteroposterior and lateral) radiographs are also required to look for intra-articular extension of fracture lines.

If intra-articular extension is suspected, a computed tomography (CT) scan must be performed. It must be obtained with frontal and sagittal reconstruction. It is useful to establish intra-articular involvement, to identify separate osteochondral fragments in the area of the intercondylar notch, and to identify coronal plane fractures (Hoffa fracture) – 38 % incidence of Hoffa fractures in type C fractures – and for preoperative planning. It is important to mention that 31 % of the coronal plane fractures are not identified by plain radiographs alone.

Identifying coronal plane fractures is paramount for preoperative planning, with regard to both surgical approach and implant selection. In high-energy distal femur fractures that will undergo temporary external fixation, it is helpful to obtain the CT scan after the knee-spanning external fixator is applied. The distraction and ligamentotaxis that the external fixator provides allows for easier visualization of fragments and better preoperative planning [5].

Angiography must be indicated when diminished distal pulses are present after gross alignment has been restored.

7.3 Surgical Treatment

The diversity of surgical options for the management of fractures of the distal femur reflects the challenges inherent in these injuries. These fractures are frequently comminuted and intra-articular, and they often involve osteoporotic bone, which makes it difficult to reduce and hold them while maintaining limb alignment (Fig. 7.1). Surgery has become the standard of care for displaced fractures [6].

The goal of surgical management is to get early knee motion while restoring the articular surface, maintaining limb length and alignment, and preserving the soft tissue envelope with a durable fixation that allows functional recovery during bone healing.

A variety of surgical exposures, techniques, and implants have been developed to meet these objectives. They include external fixation, intramedullary (IM) nailing, and plating (Figs. 7.2, 7.3, 7.4, and 7.5).

Open reduction and internal fixation (ORIF) must be indicated in displaced fractures, intra-articular fractures, and nonunions [7]. To achieve a good result, we need anatomic reduction of the joint, stable fixation of the articular component to the femoral shaft, and preservation of vascularity. Retrograde IM nail should be indicated in fractures of the distal femur without significant comminution, being the preferred implant in the osteoporotic bone.

The identified risk factors for reoperation to promote union and complications included open fracture, diabetes, smoking, increased body mass index, and shorter plate length. The majority of these factors are out of surgeon control but are useful when considering prognosis. Use of relatively long plates is a technical factor that can reduce risk for fixation failure [8].

7.3.1 ORIF Approaches

The anterolateral approach is recommended in fractures without or with simple articular extension; an incision must be made from the tibial tubercle to the anterior third of the distal femoral condyle; the approach can be extended up the midlateral femoral shaft as needed.

The lateral parapatellar approach should be used in fractures with complex articular extension; the incision can be extended into the quadriceps tendon to evert the patella.

Fig. 7.1 Supracondylar femoral fracture in an elderly patient with osteoporosis treated by plating: (**a**) Anteroposterior preoperative view. (**b**) Lateral preoperative radiograph. (**c**) Postoperative lateral view. (**d**) Anteroposterior postoperative radiograph

Fig. 7.2 A 19-year-old polytrauma patient suffered cranio-encephalic trauma, thoracic trauma, complex supracondylar femoral fracture, and ipsilateral distal tibia fracture. The femoral fracture was treated by plating and the tibial fracture by means of a locked unreamed intramedullary nail: (**a**) Lateral preoperative view. (**b**) Anteroposterior postoperative radiograph of the distal femur fracture. (**c**) Lateral postoperative view of the supracondylar femoral fracture. (**d**) Postoperative lateral view of the tibial fracture. (**e**) Anteroposterior postoperative radiograph of the tibial fracture

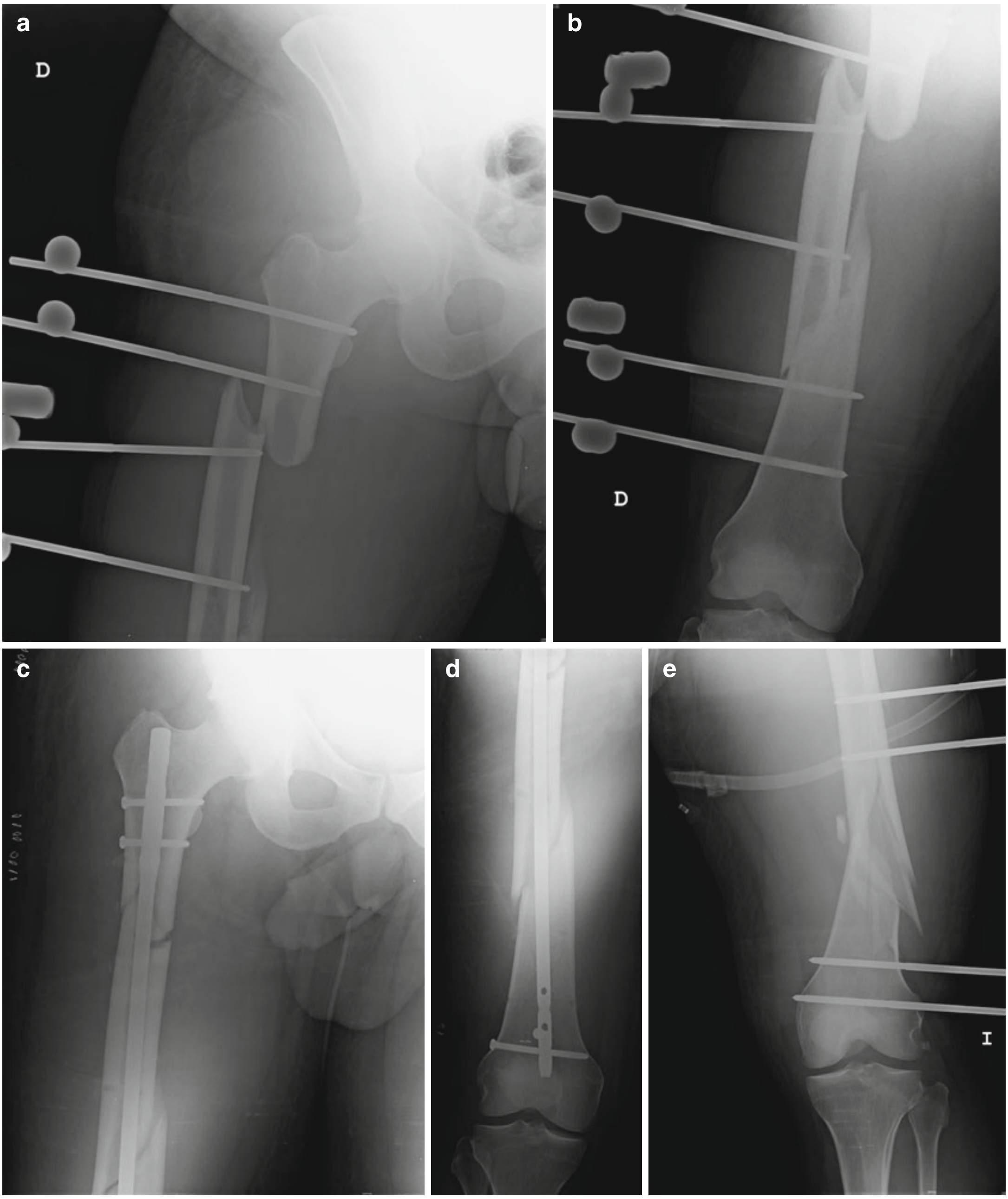

Fig. 7.3 A 39-year-old polytrauma patient suffered a bilateral femoral fracture, bifocal in the right side, and supracondylar in the left side. Both fractures were temporarily fixed by external fixators (damage control strategy). In a second procedure the fracture on the right limb was fixed with an unreamed locked intramedullary nail, while the fracture on the left side was fixed by means of plating: (**a**) Anteroposterior view of the bifocal right femoral fracture with the external fixator in place. (**b**) Distal view of the same bifocal fracture. (**c**) Anteroposterior view of the same fracture after unreamed locked intramedullary nailing. (**d**) Distal view of the same fracture with the intramedullary nail in place. (**e**) Anteroposterior view of the left femoral fracture with the external fixator in place. (**f**) Anteroposterior view of the same fracture after plating. (**g**) Lateral radiograph of the same fracture after plating

Fig. 7.3 (continued)

The medial parapatellar approach is the typical TKA (total knee arthroplasty) approach. It should be used for complex medial femoral condyle fractures.

The medial/lateral posterior approach should be used for very posterior Hoffa fragment fixation; the patient must be placed in prone position; a midline incision should be made over the popliteal fossa; then the plane between the medial and the lateral gastrocnemius muscle must be developed; and finally, capsulotomy will let us visualize the fracture.

7.3.2 External Fixation

External fixation is usually indicated in open fractures of the distal femur with bone loss, vascular injury, associated severe soft tissue injuries, or extensive comminution [9–11]. Monolateral external fixation without spanning the knee and circular or ring fixators can be used.

For fractures with articular involvement, articular reconstruction must be performed first, using either open reduction and limited internal fixation or closed reduction and percutaneous fixation with independent screws. Articular reconstruction must be then followed by application of the external fixator. Occasionally, a knee-spanning component can be used initially to augment the distal segment fixation.

Complications related to the use of external fixation for definitive treatment of fractures of the distal femur include septic arthritis, osteomyelitis, pin tract infection, loss of reduction, delayed union or nonunion requiring bone grafting, and limited knee motion requiring either manipulation

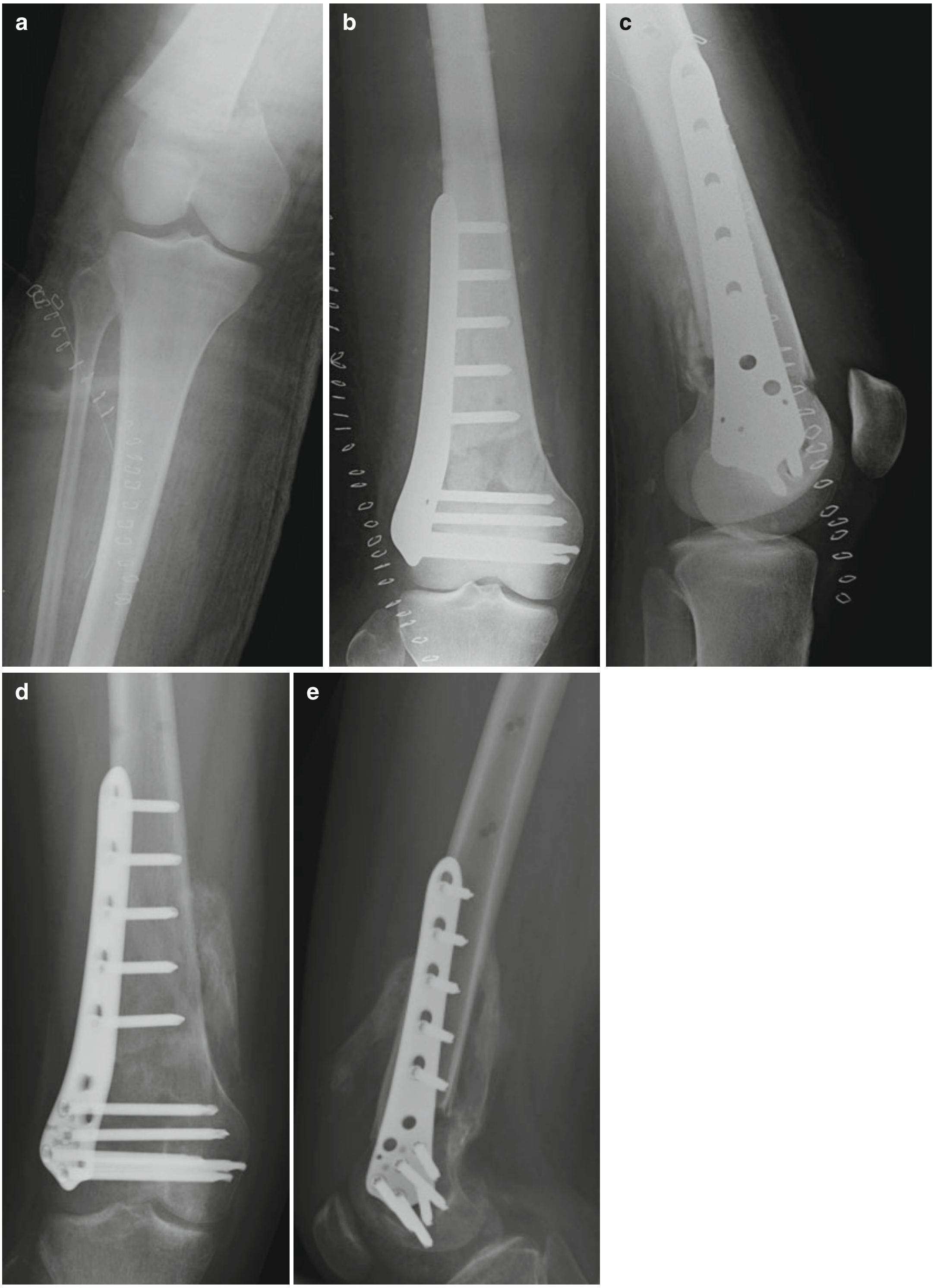

Fig. 7.4 A 32-year-old man suffered a supracondylar fracture of the femur. It was fixed by means of plating: (**a**) Anteroposterior preoperative view. (**b**) Anteroposterior postoperative radiograph. (**c**) Lateral postoperative view. (**d**) Anteroposterior radiograph after bone healing. (**e**) Lateral view after bone union

under anesthesia or quadricepsplasty. Several series have reported <10° of angular deformity and <3 cm of shortening [9, 10, 12].

Timing of external fixator removal may be difficult to determine in complex fractures. Time to bony union has been reported to require up to an average of 25 weeks [9, 11]. External fixator removal may require anesthesia and may lead to a risk of refracture. Zlowodzki et al. [13] reported an average 7.2 % nonunion rate, a 1.5 % rate of fixation failure, a 4.3 % rate of deep infection, and a 30.6 % rate of secondary surgical procedures.

The use of ring fixators is complicated by the fact that this technique is technically demanding and has a steep learning curve. Arazi et al. [10] reported that in the management of comminuted

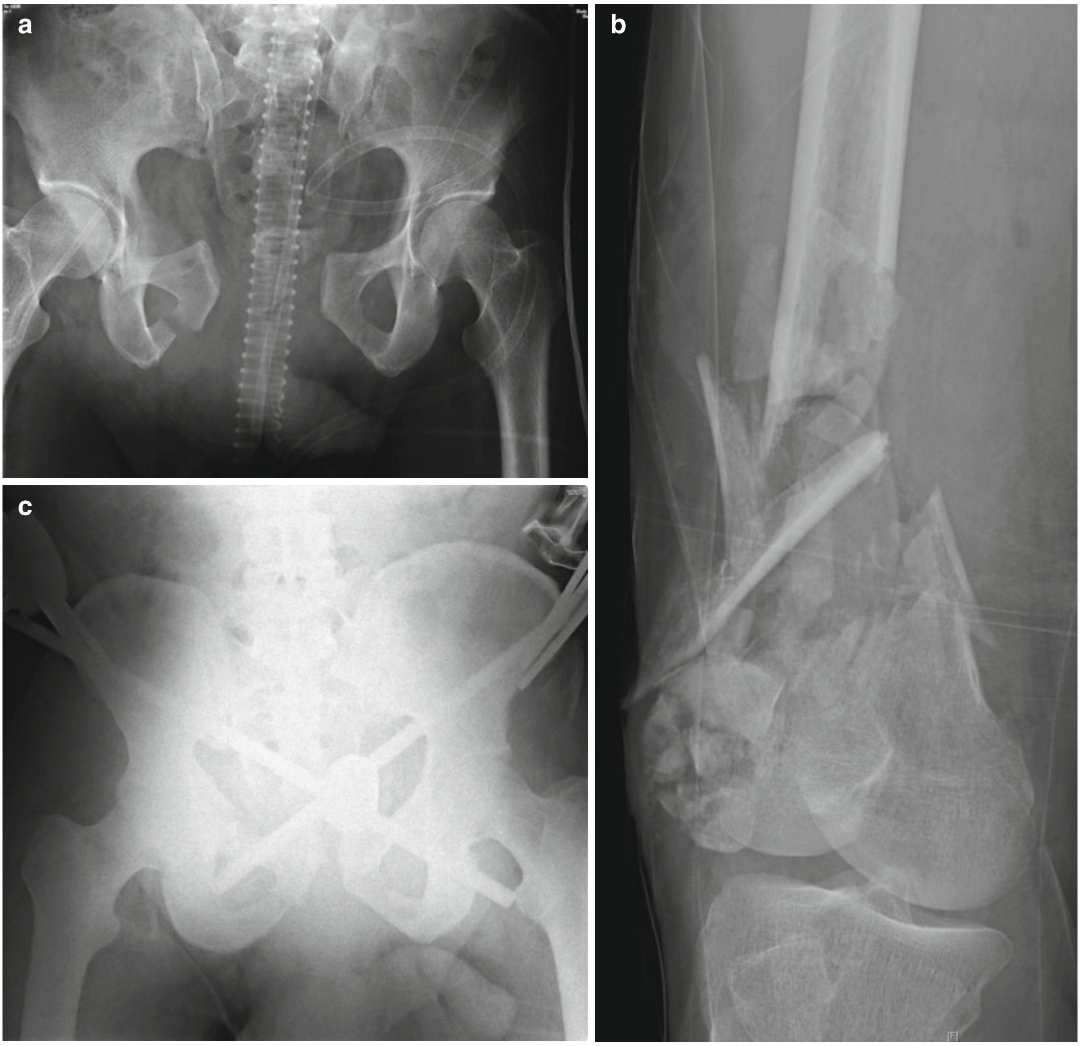

Fig. 7.5 Polytrauma patient who suffered pelvic fracture, complex supracondylar femoral fracture, and ipsilateral patellar fracture. Initially he was treated by means of damage control strategy (external fixators in pelvis and femur). In a second stage the pelvic fracture and the supracondylar fracture were fixed with plating. The patellar fracture was fixed by a figure-of-eight wiring: (**a**) Anteroposterior view of the pelvic fracture. (**b**) Anteroposterior radiograph of the supracondylar femoral fracture. (**c**) Anteroposterior view of the pelvis after external fixation. (**d**) Anteroposterior radiograph of the femur after external fixation. (**e**) Anteroposterior view of the pelvis after definitive fixation. (**f**) Anteroposterior radiograph of the femur and patella after definitive fixation. (**g**) Lateral view of distal femur and patella after fixation. (**h**) AP long-standing radiograph of the lower limbs showing the final result

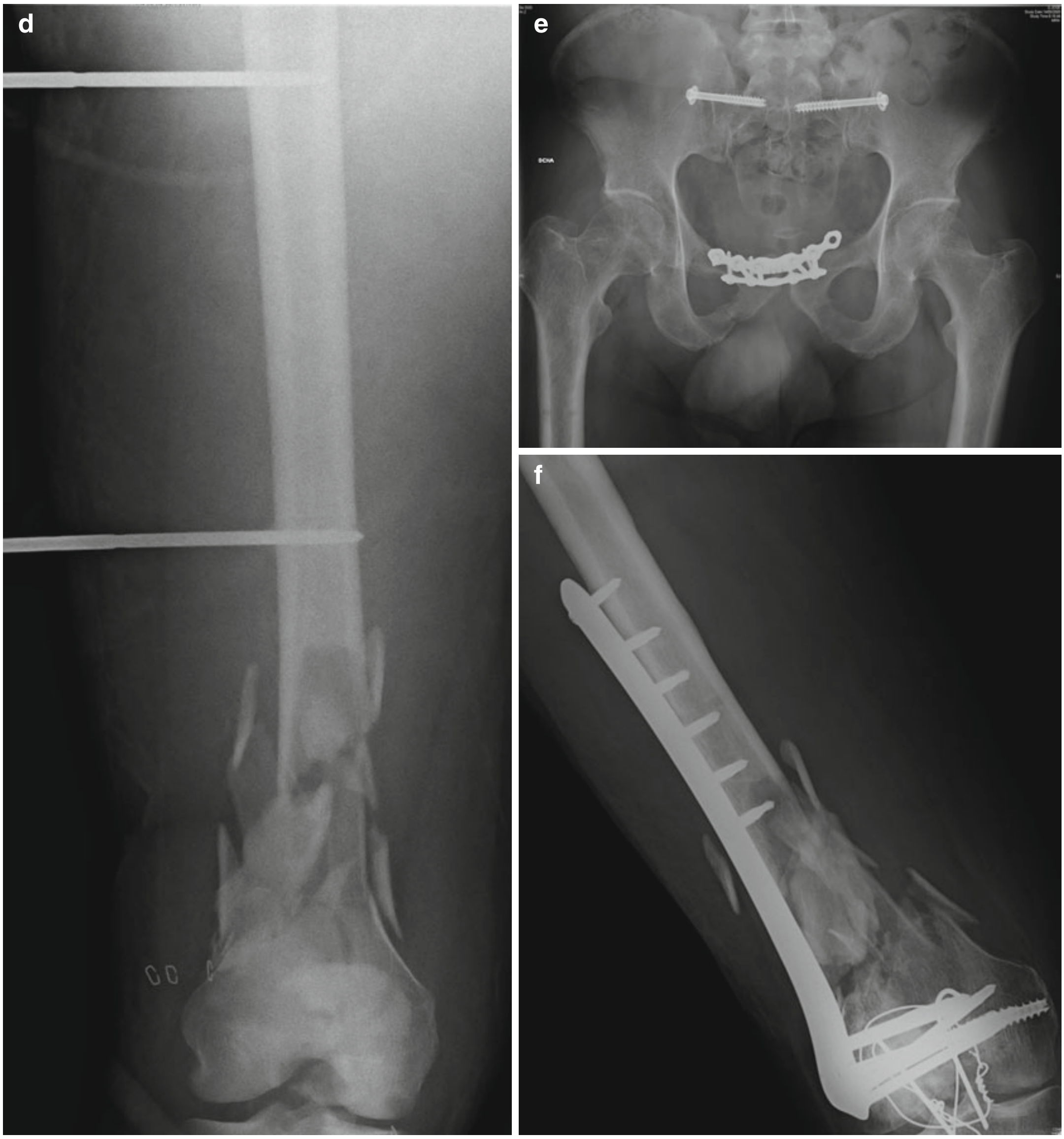

Fig. 7.5 (continued)

Fig. 7.5 (continued)

fractures of the distal femur, the Ilizarov fixator is safe and effective in providing stability and allowing early rehabilitation.

7.3.3 Plating

Blade-plate fixation (95°-angled blade plate) is no longer used today; in fact, it is contraindicated in type C3 fractures. The dynamic condylar screw (DCS) has the same indications with that of the 95°-angled blade plate. From the technical point of view, precise sagittal plane alignment is not necessary; the DCS must be placed 2.0 cm from the articular surface. An important disadvantage of DCS is that a large amount of bone must be removed.

Locking condylar plate (LCP) has an important advantage: that the fixed-angle locked screws provide improved fixation in short distal femoral segments. The lag screws with locked screws result in a hybrid construct that is useful for intercondylar fractures (usually in conjunction with locked plate); it also helps obtain anatomic reduction of the knee which is required in displaced articular fractures.

Several biomechanical studies compared conventional fixed-angle implants (nonlocking plates) and locking plates in supracondylar (ASIF/OTA A3) fracture models. Marti et al. [14]

compared the LISS (less invasive stabilization system) plate with unicortical locking screws to the dynamic condylar screw and condylar buttress plate in axial loading and cyclic axial loading to failure in a cadaveric 1-cm fracture gap model. The LISS had more reversible and less irreversible deformation when compared to the other two constructs, which they attributed to the titanium composition and the unicortical screws.

Zlowodzki et al. [13] compared the LISS plate with unicortical locking screws to the 95° blade plate in axial, torsional, and cyclic axial loading in a cadaveric 1-cm fracture gap model. The blade plate was significantly stiffer in torsion. However, the LISS plate had significantly less permanent deformation under cyclic axial loading. Therefore, it appeared that the LISS provides improved distal fixation in osteoporotic bones. In a 4-cm fracture gap model in high bone density cadaveric specimens, no significant difference was found between the LISS plate with unicortical locking screws and the angled blade plate for axial load to failure, but the LISS plate had significantly less axial stiffness [13].

Higgins et al. [15] compared the LCP, with distal locking screw fixation and bicortical locking and nonlocking diaphyseal fixation, to the angled blade plate in axial load to failure and cyclic axial loading in a cadaveric 1-cm fracture gap model. The locking construct had a significantly higher load to failure and less permanent deformation with cyclic loading. All of these studies reveal that locking plates with unicortical or bicortical diaphyseal fixation have adequate axial stiffness but more flexibility when compared to conventional fixed-angle implants. Although they have less torsional stiffness, the studies that evaluated torsional stiffness demonstrated that the distal fixation in locked implants is typically maintained, while conventional fixed-angle implants have a higher rate of distal cutout from the femoral condyles.

In complex fractures of distal femur with a deficient medial-cortical buttress, stability may not be achieved with a lateral condylar buttress plate alone. When collapse of the distal fragment into varus angulation is noted intraoperatively, with the axis of rotation being the junction of the distal screws and the plate, additional stabilization with a medial plate and a bone graft from the iliac crest should be applied [16].

Complex fractures of the distal femur can be treated using an indirect plate fixation technique and a lateral parapatellar arthrotomy for the direct reduction of the condylar segment [17]. Following reconstruction of the articular segment, the segment must be indirectly reduced and fixed to the shaft by a plate inserted by the retrograde method beneath the vastus lateralis.

Transcutaneous/transmuscular screws must be then used to fix the plate to the shaft. The results obtained with this technique compared favorably with other reported series using different techniques without the added morbidity associated with autogenous bone grafting. However, the surgical technique is demanding and special care must be taken to ensure correct axial alignment.

Multiplanar complex C3-type unstable fractures of the distal femur present many challenges in terms of approach and fixation. Khalil and Ayoub [18] used double plating with autogenous bone grafting via a modified Olerud extensile approach. Use of this modified highly invasive approach facilitated anatomical reconstruction of C3-type complex fractures of the distal femur with lower expected complication rate and acceptable clinical outcome. It can be considered as a standby solution for managing these difficult injuries.

An important complication is symptomatic hardware; in lateral plates we can find pain with knee flexion/extension due to iliotibial band contact with plate; medial screw irritation may also be found due to excessively long screws that can irritate medial soft tissues. It is paramount to determine appropriate intercondylar screw length by obtaining an anteroposterior radiograph of the knee with the leg internally rotated 30°.

Malunions is most commonly associated with plating; functional results may be satisfactory if malalignment is within 5° in any plane. In case of nonunions treatment with revision ORIF and autogenous graft must be indicated; we should also consider changing fixation technique to improve biomechanics.

7.3.4 Interlocked Intramedullary (IM) Nail

This technique is good for fractures of the distal femur without significant comminution; in fact, it is our preferred implant in osteoporotic bone; the surgical approach must be medial parapatellar. When no articular extension is present, a 2.5-cm incision parallel to medial aspect of patellar tendon must be done staying inferior to the patella.

No attempt must be made to visualize the articular surface. When articular extension is present, the approach must be continued 2–8 cm cephalad incising the extensor mechanism 10 mm medial to the patella; eversion of the patella is not typically necessary. The main advantage of this technique is that it requires minimal dissection of soft tissues. The main disadvantages, however, are that less axial and rotational stability is achieved, and that postoperative knee pain is common.

Complications related to retrograde IM nailing include nonunion (5.3 % rate), fixation failure (3.2 % rate), deep infection (0.4 % rate), and secondary procedure rate (24.2 %) [13]. Other complications are anterior knee pain, injury to the deep femoral artery with proximal locking, iatrogenic fracture of the femoral shaft, stress fracture above the implant, fatigue failure of the nail, intra-articular impingement of the nail, distal interlock bolt breakage, and varus malalignment requiring osteotomy correction.

Functional outcomes have been shown to correlate with patient age and severity of the initial injury. Studies that included fractures with articular involvement used closed or open reduction of the articular surface with supplemental fixation prior to nailing. To improve distal fixation, authors have recommended longer nails with more distal positioning or cutting the distal end of the nail to allow for more distal placement of the interlocking holes [19–21].

Complications with antegrade IM nailing in fractures of the distal femur include painful distal interlocking bolts, malunion, limb shortening >1 cm, and nail breakage. The systematic literature review of antegrade IM nailing for distal femur fractures reported by Zlowodzki et al. [13] revealed a nonunion rate of 8.3 %, a fixation failure rate of 3.7 %, an infection rate of 0.9 %, and a 23.1 % rate of secondary procedures.

7.3.5 Total Knee Arthroplasty (TKA)

A controversy still exists for elderly osteoporotic patients with poor fracture healing potential. TKA has been used in an attempt to solve this difficult situation. Rosen and Strauss [22] reviewed the use of two different distal femoral replacement rotating hinge total knee prostheses in 24 patients, averaging 76 years old. Twenty-three fractures were ASIF/OTA type C and one was type B. Five patients had preexisting osteoarthritis. All patients regained ambulatory and full weight-bearing status. Seventy-one percent of patients regained prefracture ambulatory aid requirements. No prosthetic loosening or revisions were found with an average follow-up of 11 months. They reported 1 superficial infection that resolved with antibiotics, 1 dislocation of the hinged prosthesis after a fall, and 1 cardiac-related death 13 months postoperatively. The reported benefits of this technique include early weight bearing and knee motion, fewer complications, and fewer revision surgeries than internal fixation. Primary TKA appeared to be effective in elderly patients with articular fractures and significant osteoporosis, preexisting osteoarthritis, restricted lifestyles, and limited treatment expectations [22].

7.4 Periprosthetic Fractures of the Distal Femur

The osteosynthesis of the periprosthetic fractures following a TKA or a total hip arthroplasty (THA) can be technically difficult with relatively small satisfactory results and high complication rates (Fig. 7.6).

Several methods have been described to stabilize periprosthetic fractures following a TKA [23]. In fractures of the distal femur around a stable implant (Rorabeck type I and II), it is recommended to use plates and retrograde IM nails

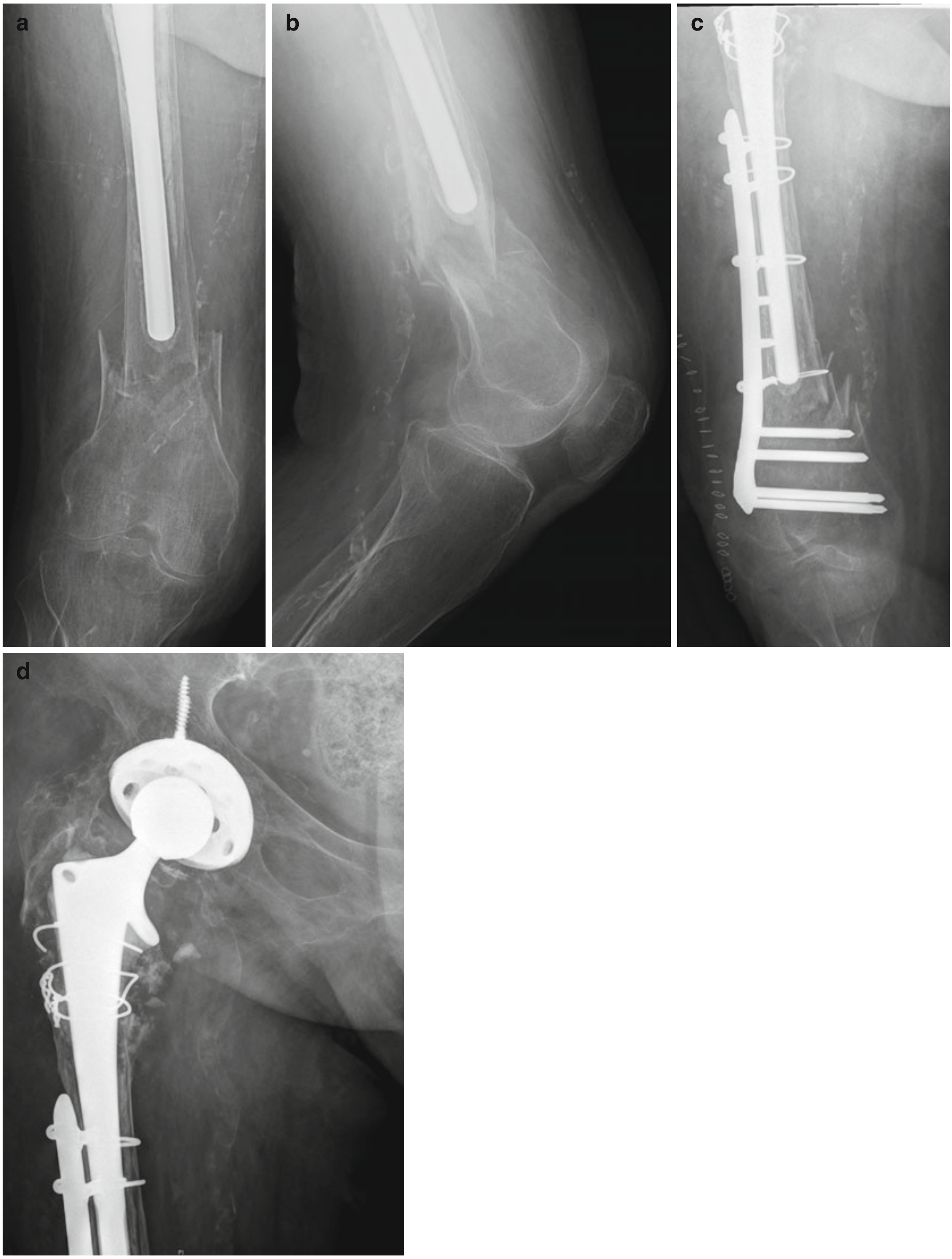

Fig. 7.6 Periprosthetic fracture of the distal femur in an elderly patient with a total hip prosthesis implanted 4 years before. The fracture was fixed by means of a long femoral plate: (**a**) Anteroposterior view of the periprosthetic fracture. (**b**) Lateral radiograph of the same fracture. (**c**) Anteroposterior view after plating. (**d**) Anteroposterior radiograph after plating of the periprosthetic fracture showing the proximal part of the plate and the previously implanted total hip prosthesis

(in Rorabeck I or II with an open box of a TKA). For reduction, three methods can be used: the open technique (with direct or indirect reduction), the mini open technique (direct reduction of the fracture by cerclage or lag screw and percutaneous plate fixation in ASIF/OTA- type 32 or 33-A1), and the minimally invasive technique (indirect reduction and percutaneous fixation in all other ASIF/OTA types). Fractures with a loose prosthesis (Rorabeck III) are best stabilized by hinged revision arthroplasty.

Gavaskar et al. [24] analyzed the midterm results following the locked plating of periprosthetic fractures of the distal femur after a TKA. Successful union was achieved in 18 of the 19 patients available for the follow-up. The mean follow-up was 39 months. Significant reductions in the range of motion and WOMAC scores were evident in the follow-up. Secondary procedures were required in five patients to address the delay in union and the reduced knee range of motion. The osteosynthesis failed in one patient who underwent a revision TKA.

Saidi et al. [25] reviewed three different treatment methods for treating comminuted periprosthetic fractures of the distal femur in 23 patients over the age of 70 (average age 80). Reconstruction techniques included seven allograft prosthesis composite, nine revision systems, and seven distal femur endoprosthesis. Their preliminary results demonstrated that distal femur endoprosthesis should be considered in patients with advanced age and poor bone quality who require early mobilization.

Horneff et al. [26] compared retrograde IM femoral nailing with supracondylar locked screw-plate fixation for the treatment of periprosthetic fractures of the distal femur following TKA. Their results supported the use of a laterally based locked plate in the treatment of Rorabeck type II periprosthetic fracture of the distal femur.

7.5 Evidence-Based Medicine

In 2006, Zlowodzki et al. [13] reported a systematic review of the literature from 1989 to 2005 for operative treatment of acute fractures of the distal femur. The levels of evidence for studies included in the meta-analysis ranged from 2 to 4. Evidence-based recommendations were given. A grade B recommendation was given for operative treatment over nonoperative treatment. Operative treatment reduced the risk of poor results by 32 %. For the type of internal fixation used, a grade C recommendation was given. There were no observed differences between implants for nonunions, fixation failures, infections, and revision surgeries. Subgroup analysis showed that submuscular locked plating may reduce the rate of infection when compared to compression plating (55 % relative risk reduction), but at the increased risk of fixation failure and revision surgery. In addition, increased surgeon experience may significantly reduce the risk of revision surgery.

Krijnen et al. [27] stated in 2012 that even though the overall level of evidence in the literature is very low (expert opinions), the use of CT scans or 3D reconstructions can be considered for standard use in the management planning of fractures of the distal femur. Regarding the optimal type of fixation, the use of either a retrograde IM nail or plate fixation must be guided by orthopedic surgeon experience (overall level of evidence is low). Concerning what is the best type of plate fixation, the overall level of evidence is also low. The rates of deep infection and nonunion are similar in locking plates with that of traditional plates (blade plate, DCS). In periprosthetic fractures the level of evidence is very low. Retrograde IM nailing and locking plates appear to be more successful than nonlocking plates [27].

Conclusions

ASIF/OTA 33-C3 distal femur fracture is characterized by complex articular involvement and is often accompanied by a very short distal femur segment, small osteochondral fragments, and high-energy soft tissue disruption. Current fixation strategies do not provide for optimal reduction of the articular surface in conjunction with stable fixation of the distal femoral segment.

The use of either a retrograde IM nail or plate fixation in complex fractures of the distal femur must be based on orthopedic surgeon experience. Concerning what is the best type of plate fixation, the current trend is to use locking plates. However, the rates of deep infection and nonunion are similar in locking plates with that of traditional plate fixation (blade plate, DCS).

External fixation is usually reserved for open fractures of the distal femur with bone loss, vascular injury, associated severe soft tissue injuries, or extensive comminution. Monolateral external fixation without spanning the knee and circular or ring fixators can be used.

Malunion, loss of fixation, need for supplemental fixation, and need for bone grafting are common in the treatment of the C3 distal femur fracture.

In periprosthetic fractures retrograde IM nailing and locking plates appear to be more successful than nonlocking plates. Distal femur endoprosthesis should be considered in patients with advanced age and poor bone quality who require early mobilization.

References

1. Martinet O, Cordey J, Harder Y, Maier A, Buhler M, Barraud GE (2000) The epidemiology of fractures of the distal femur. Injury 31(Suppl 3):C62–C63
2. Albert MJ (1997) Supracondylar fractures of the femur. J Am Acad Orthop Surg 5:163–171
3. Stover M (2001) Distal femoral fractures: current treatment, results and problems. Injury 32(Suppl 3): SC3–SC13
4. Fracture and dislocation compendium. Orthopaedic Trauma Association Committee for Coding and Classification (1996) J Orthop Trauma 10(Suppl 1): v–ix, 1–154
5. Nork SE, Segina DN, Aflatoon K et al (2005) The association between supracondylar-intercondylar distal femoral fractures and coronal plane fractures. J Bone Joint Surg Am 87(3):564–569
6. Fernández-González J, Ponce SJ, Fole R, Blanco-Ortiz F (2013) Fractures of distal femur. In: Rodríguez-Merchán EC (ed) Traumatic injuries of the knee. Springer, Milan/New York
7. Rubio-Suárez JC (2013) Nonunion and malunion around the knee. In: Rodríguez-Merchán EC (ed) Traumatic injuries of the knee. Springer, Milan/New York
8. Ricci WM, Streubel PN, Morshed S, Collinge C, Nork SE, Gardner MJ (2014) Risk factors for failure of locked plate fixation of distal femur fractures: an analysis of 335 cases. J Orthop Trauma 28:83–89
9. Hutson JJ Jr, Zych GA (2000) Treatment of comminuted intraarticular distal femur fractures with limited internal and external tensioned wire fixation. J Orthop Trauma 14:405–413
10. Arazi M, Memik R, Ogun TC, Yel M (2001) Ilizarov external fixation for severely comminuted supracondylar and intercondylar fractures of the distal femur. J Bone Joint Surg Br 83:663–667
11. Ali F, Saleh M (2000) Treatment of isolated complex distal femoral fractures by external fixation. Injury 31:139–146
12. Marsh JL, Jansen H, Yoong HK, Found EM Jr (1997) Supracondylar fractures of the femur treated by external fixation. J Orthop Trauma 11:405–410
13. Zlowodzki M, Bhandari M, Marek DJ, Cole PA, Kregor PJ (2006) Operative treatment of acute distal femur fractures: systematic review of 2 comparative studies and 45 case series (1989 to 2005). J Orthop Trauma 20:366–371
14. Marti A, Fankhauser C, Frenk A, Cordey J, Gasser B (2001) Biomechanical evaluation of the less invasive stabilization system for the internal fixation of distal femur fractures. J Orthop Trauma 15:482–487
15. Higgins TF, Pittman G, Hines J, Bachus KN (2007) Biomechanical analysis of distal femur fracture fixation: fixed-angle screw-plate construct versus condylar blade plate. J Orthop Trauma 21:43–46
16. Sanders R, Swiontkowski M, Rosen H, Helfet D (1991) Double-plating of comminuted, unstable fractures of the distal part of the femur. J Bone Joint Surg Am 73:341–346
17. Krettek C, Schandelmaier P, Miclau T, Bertram R, Holmes W, Tscherne H (1997) Transarticular joint reconstruction and indirect plate osteosynthesis for complex distal supracondylar femoral fractures. Injury 28(Suppl 1):A31–A41
18. Khalil A-S, Ayoub MA (2012) Highly unstable complex C3-type distal femur fracture: can double plating via a modified Olerud extensile approach be a standby solution? J Orthop Traumatol 13:179–188
19. Dominguez I, Moro Rodriguez E, De Pedro Moro JA, Cebrian Parra JL, Lopez-Duran Stern L (1998) Antegrade nailing for fractures of the distal femur. Clin Orthop Relat Res 350:74–79
20. Butler MS, Brumback RJ, Ellison TS, Poka A, Bathon GH, Burgess AR (1991) Interlocking intramedullary nailing for ipsilateral fractures of the femoral shaft and distal part of the femur. J Bone Joint Surg Am 73:1492–1502
21. Leung KS, Shen WY, So WS, Mui LT, Grosse A (1991) Interlocking intramedullary nailing for supracondylar and intercondylar fractures of the distal part of the femur. J Bone Joint Surg Am 73: 332–340
22. Rosen AL, Strauss E (2004) Primary total knee arthroplasty for complex distal femur fractures in elderly patients. Clin Orthop Relat Res 425: 101–105

23. Ruchholtz S, Tomás J, Gebhard F, Larsen MS (2013) Periprosthetic fractures around the knee-the best way of treatment. Eur Orthop Traumatol 4:93–102
24. Gavaskar AS, Tummala NC, Subramanian M (2013) The outcome and complications of the locked plating management for the periprosthetic distal femur fractures after a total knee arthroplasty. Clin Orthop Surg 5:124–128
25. Saidi K, Ben-Lulu O, Tsuji M, Safir O, Gross AE, Backstein D (2014) Supracondylar periprosthetic fractures of the knee in the elderly patients: a comparison of treatment using allograft-implant composites, standard revision components, distal femoral replacement prosthesis. J Arthroplasty 29:110–114
26. Horneff JG 3rd, Scolaro JA, Jafari SM, Mirza A, Parvizi J, Mehta S (2013) Intramedullary nailing versus locked plate for treating supracondylar periprosthetic femur fractures. Orthopedics 36:e561–e566
27. Krijnen MR, Goslings JC, Poolman RW (2012) Distal femur fractures. In: Bhandari M (ed) Evidence-based orthopedics, 1st edn. Blackwell Publishing Ltd, Oxford, pp 522–526

Complex Fractures of the Proximal Tibia

8

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and E. Carlos Rodríguez-Merchán

8.1 Introduction

Complex fractures of the proximal tibia are difficult to treat due to the comminution and associated injuries, such as meniscal and ligamentous tears, lesions of the peroneal nerve or the popliteal vessels, and severe skin damage. Preoperative planning is essential and the state of the soft tissue marks the time of surgery. These fractures have been associated with high complication rates. Recognizing and managing the soft tissue components of tibial plateau injuries may be the most important aspects of the treatment and ultimate outcome. The goals of treatment are the decompression and preservation of the soft tissue, reconstruction of the articular surfaces, restitution of normal mechanical axis, and early mobilization.

8.2 Classification

Complex tibial plateau fractures are usually described as Schatzker et al. [1] types IV, V, and VI or as a Type C injury when using the AO/Orthopaedic Trauma Association classification [2]. Tibial plateau fractures belong to the segment number 41 of the AO/Orthopaedic Trauma Association classification.

Type C fractures affect both condyles with articular and metaphyseal strokes:

- C-1: simple articular and metaphyseal fracture
- C-2: simple articular and complex metaphyseal fracture
- C-3: complex articular and metaphyseal fracture

Schatzker classification is perhaps the most used today and divides plateau fractures into two groups with three types in each group. The second group consists of high-energy fractures:

- IV fracture of the medial condyle. It is rare but is frequently accompanied by neurovascular injuries, compartment syndrome, and/or ligament lesion. The medial condyle fractures differ from lateral condyle in which more energy is required to produce them.
- V bicondylar fracture without metaphyseal involvement.
- VI fracture of both condyles and metaphyseal.

Schatzker and the AO/OTA systems are based on two-dimensional classification systems. Some fracture patterns are incompletely classified, such as posterior shearing fractures of the tibial plateau. A new classification improves the understanding of more complex fracture patterns. The three-column classification is based on the CT (computed tomography) scan and on the three-dimensional (3-D) reconstruction as a supplement to the Schatzker classification. Three-column classification [3] takes a transverse view and the

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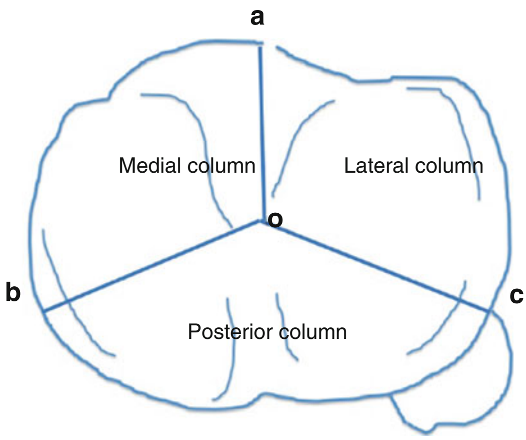

Fig. 8.1 Three-column classification of fractures of the proximal tibia. *Point A* is the anterior tibial tuberosity. *Point O* is the midpoint of the two tibial spines. *Point C* is the most anterior point of the fibular head and *point B* represents the medial–posterior ridge of the tibial plateau. The tibial plateau is divided into three parts which represent the lateral column, medial column, and posterior column, respectively

tibial plateau is divided into three areas, which are defined as the lateral column, the medial column, and the posterior column (Fig. 8.1). The classification can help surgeons for the diagnosis and preoperative planning providing a better approach and fixation methods.

8.3 Clinical Assessment

Patients who have sustained a high-energy injury require a special evaluation, through advanced trauma life support (ATLS) protocols. First treat injuries that are potentially life threatening, and once stabilized, evaluate orthopedic injuries.

The evaluation and documentation of neurological status, vascular status, and soft tissues is essential in these fractures.

- Neurological examination focuses on the function of the peroneal nerve, which is the most vulnerable in the medial plateau fractures and high-energy fractures and is stretch on their way around the neck of the fibula. The tibial nerve is located in close proximity to the site of injury and also to be evaluated.
- Vascular examination focuses on the popliteal artery, which can be injured by traction, debuting as a thrombosis, or may be sectioned by posteriorly displaced fracture fragments. If pulses are not palpable, use an echo Doppler. If there is any question of vascular injury, ankle–brachial index is obtained. If less than 0.9 or physical examination (capillary refill, color, and skin temperature) findings suggest vascular injury, CT angiography and vascular surgical consultation should be performed (Fig. 8.2).

Fig. 8.2 Angio-CT of complex fracture of the proximal tibia with stop in the popliteal artery

- The skin is inspected circumferentially. Contusion, blisters, and swelling are common in high-energy fractures. Open lesions should be excluded. We can inject methylene blue into the joint to assess whether there is communication between the joint and skin lacerations. In our center we photograph any injury to the skin. The Gustilo–Anderson et al. [4] classification and Tscherne and Gotzen [5] classification are used for, respectively, open and closed fractures.

The knee stability should be evaluated to rule out ligament disruption although this assessment can be difficult preoperatively owing to difficulty differentiating ligamentous from bony instability.

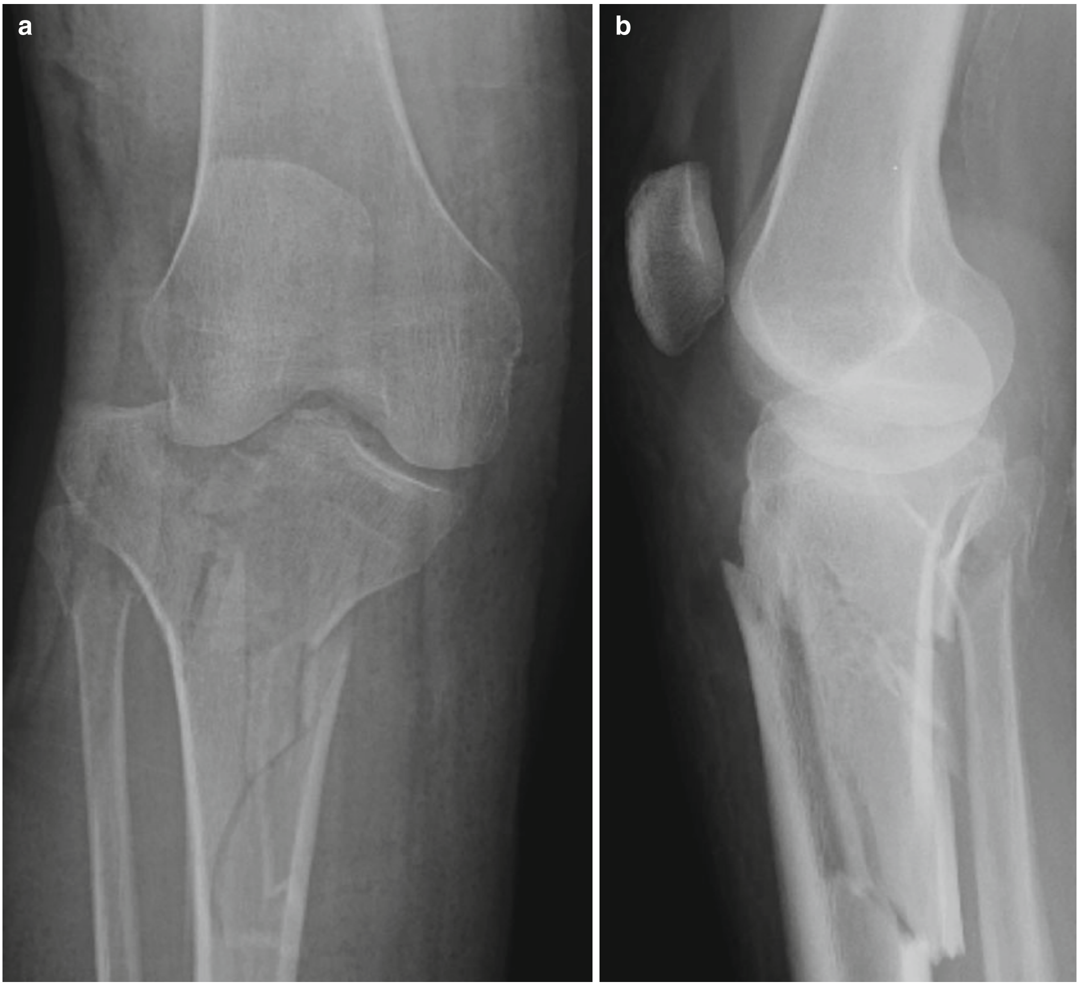

Fig. 8.3 Anteroposterior (**a**) and lateral (**b**) views of a tibial plateau fracture

The examination should be delayed until the time of surgery to prevent the patient's pain and after bone stability. We must also rule out knee dislocation, heightening the importance of a thorough neurovascular examination and the need for preoperative MRI (magnetic resonance imaging).

The compartment syndrome is a terrible complication, diagnosis and early treatment is essential. We must have a high level of clinical suspicion for compartment syndrome in high-energy plateau fractures, especially types V and VI [6]. Measuring the pressure of the compartments (pressures within 30 mmHg of the diastolic blood pressure) can be useful for diagnosis, but the clinical scene is prevalent (6 Ps: pain out of proportion, pain with passive stretch of muscle groups in the leg, pressure, paresthesias, paralysis, and pulselessness). The management must be urgent through fasciotomies of the four leg compartments.

8.4 Radiological Assessment

Standard preoperative radiographic evaluation includes radiographs and CT.

Most high-energy fractures of the tibial plateau are easy to identify in standard anteroposterior (AP) and lateral views of the knee. The AP projection allows us to classify the fracture. The lateral projections provide a better assessment of coronal fractures (Fig. 8.3).

The CT scan is compelling for the precise diagnosis of tibial plateau fractures. Chan et al. [7] demonstrated that taking CT scans in addition to plain radiographs affected fracture classification, and thus the surgical plan, in >25 % of cases.

Fine-cut (2–2.5 mm) and especially three-dimensional reconstruction allows us to know the fracture and to plan surgery and surgical approaches accurately.

The CT scans were performed after bridging external fixation had been applied; this was much more informative for decision-making. If there is suspicion of vascular injury or compartment syndrome, CT angiography must be performed, which is faster and less invasive and has less radiation than arteriography.

The role of MRI in acute fracture management is controversial. High-energy tibial plateau fractures are often accompanied by ligamentous and meniscal tears. There is scant evidence that its routine use impacts on outcomes. Furthermore, incompatible external fixators often preclude the use of MRI with these injuries. The formal role of MRI in these fractures has yet to be defined [8].

8.5 Treatment

8.5.1 Timing of Treatment

Open fractures with compartment syndrome and vascular injury must be treated immediately. However, patients with multiple injuries, especially those with head, thoracic, or abdominal injuries, must be stabilized provisionally using an external fixator (damage control orthopedics) until the general conditions improve (window of opportunity, 5–10 days after injury). On the other hand, closed fractures with severe damage of soft tissues should not undergo open reduction and internal fixation immediately; in such cases we must do a sequential treatment [9]. This sequential treatment algorithm has evolved from that used for tibial plafond fractures. Egol et al. [10] report low rate (5 %) of deep wound infection in 57 high-energy tibial plateau fractures treated with this protocol.

First, we must stabilize the fracture provisionally by means of an external fixator performing indirect reduction via ligamentotaxis and restoration of limb length. In this way we await resolution of soft tissue injury and relief of pain (Fig. 8.4).

The external fixator spans the knee joint with two femoral pins, proximal to the suprapatellar pouch, and two tibial pins. Tibial pins (5 × 170 mm) must be implanted in the anteromedial surface, nearly perpendicular to the bone surface. Pins must be placed remote from anticipated skin incisions and anticipated implants. Femoral pins (5 × 170 0 200 mm) can be placed anteriorly, laterally, or anterolaterally. Lateral pins avoid loss of knee motion due to scarring of the quadriceps, but the frame is mechanically inferior to that of anterior pins. The stability can improve by stacking the frame. The connector clamps must be placed outside of fracture to allow images of the reduced fracture without interference.

8.5.2 Definitive Treatment

Nonoperative treatment for these high-energy injuries has a role in a medically decompensated patient only. These injuries have poor outcomes with nonoperative treatment [8].

The definitive internal fixation in close fractures should be performed when the soft tissues are improved (normally in 2 or 3 weeks). This can be evaluated by the decrease of inflammation, the perimeter of the leg, and the return of the ability of the skin to wrinkle.

The new plates have afforded more biological approaches to these fractures. The use of fixed-angle locking plates avoids periosteal dissection. Locking plates can be inserted submuscularly through a limited incision with percutaneously placed locking screws to minimize soft tissue injury. Indications for locking plates are not fully developed; the cost–benefit ratio should be weighed in each case [11].

8.5.2.1 Medial Plateau Fractures

These fractures affect the medial tibial plateau. There is high frequency of soft tissue, ligament, and neurovascular injuries associated with these fractures. Surgical treatment is preferred in most cases through a posteromedial approach. The medial incision started 1 cm posterior to the posteromedial edge of the tibia, and the proximal extension parallel to the pes anserinus tendons

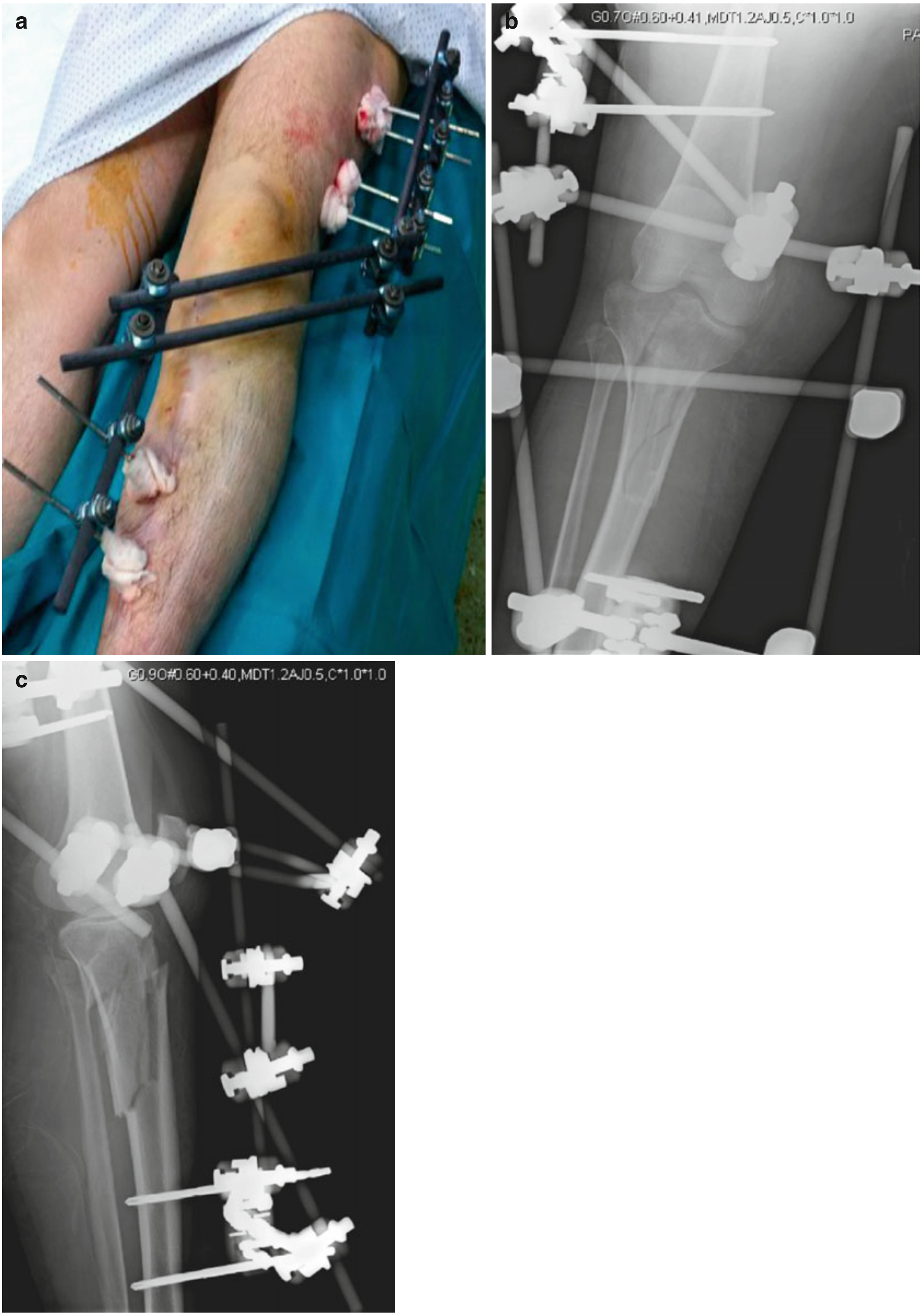

Fig. 8.4 Clinical view of a temporary spanning external fixator (**a**). In (**b**, **c**) indirect reduction via ligamentotaxis and restoration of limb length can be seen

should be as posterior as possible in order to reduce the posterior fragment. The pes tendons can be retracted or cut and repaired at the end of the procedure. The medial gastrocnemius is dissected from the tibia. A buttress plate is necessary to improve stability after open reduction (Fig. 8.5).

The repair of associated soft tissue injuries is determined on an individual basis. Meniscal injuries should be repaired whenever possible. Osseous avulsion of ligaments can be directly repaired with sutures or screws. Further ligament reconstructions are best delayed until bone healing has occurred and knee range of motion has returned [11].

8.5.2.2 Bicondylar Tibial Plateau Fractures

These fractures affect both lateral and medial tibial plateaus. The preferred treatment of these fractures is open reduction and internal fixation through two approaches: anterolateral and posteromedial. The use of the two-incision approach offers the benefits of direct visualization, reduction, and stabilization of medial and lateral articular and metaphyseal fragments while minimizing extraneous soft tissue dissection and potentially decreasing wound complications and deep sepsis previously reported with a single anterior incision [12, 13].

Anatomical reduction to restore the joint surface and the limb alignment is mandatory. Isolated lateral plating of bicondylar tibial plateau fractures using conventional plates is frequently insufficient in maintaining axial alignment [14]. In a lot of high-energy fractures the medial fragment, which is comminuted or not reducible. Then, the screws from a lateral plate cannot engage this fragment. Therefore, separate medial fixation is required. Bilateral dual plating is usually recommended as the definite fixation for this kind of fracture (Fig. 8.6), but may need an additional plate to fix the posterior column. Three-column fixation is a new fixation concept in treating complex tibial plateau fractures, which is especially useful for multiplanar fractures involving the posterior column [3].

Generally, the medial column is approached first using a posteromedial approach. Care must be taken to avoid screw fixation of unreduced lateral fracture fragments. Lou et al. [15] use the "reversed L-shaped" posterior approach to reduce directly and buttress posterior fragments.

The anterolateral approach is used to reduce and fixate the fracture in the lateral column. We identified the tubercle of Gerdy, tibial crest, patella, and fibular head. A longitudinal curvilinear skin incision is centered on the tubercle of Gerdy extending along the lateral femoral epicondyle and extending distally 1 cm lateral to the tibial crest, expose the iliotibial band and anterior compartment fascia and anterior and posterior retraction to expose the proximal tibia. The arthrotomy is performed through a submeniscal approach pass menisco-capsular sutures. More late we develop fracture line, freeing peripheral rim of the fragment like an open book, and tamping-up of the depressed articular fragment. Then, bone void filling with either allograft or autograft. Our opinion is that synthetic graft is superior. The peripherial rim is reduced (book closed), menisco-capsular sutures through the plate and put screws. Locking plates are commonly used for complex periarticular fractures, but its main use is for fixation in osteoporotic bone. A minimum of four locked screws should be used in the proximal and distal segments.

In complex fractures with severe damage of soft tissues, many authors advise the use of hybrid external fixation [16]. The hybrid construction is made with tensile wires and ring in the proximal tibia and threatened pins in the tibial shaft, all of them through percutaneous insertion. The surface reduction can be checked by arthroscopic view. The hybrid external fixation can be combined with internal fixation through percutaneous cannulated screws. This minimally invasive method provides good result because it does not add damage to the injured soft tissues [17].

8.5.2.3 Special Situations

The management of open fractures and high-energy fractures in the tibial plateau with associated compartment syndrome represents a challenge. In both cases, emergency surgery is required. Irrigation, debridement, and appropriate antibiotic or fasciotomy opening the four com-

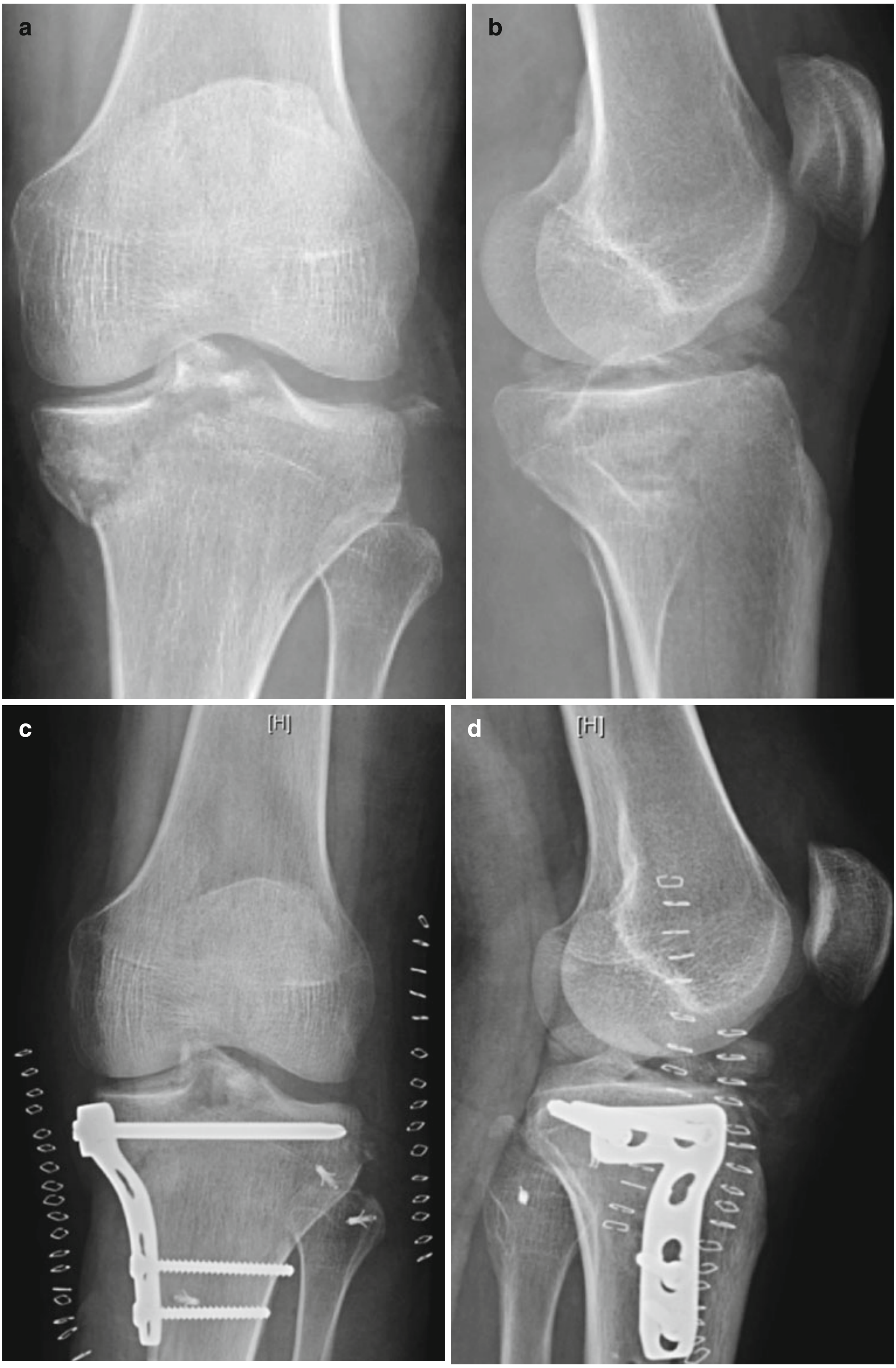

Fig. 8.5 Medial column fracture: anteroposterior (**a**) and lateral (**b**) views. The same fracture with medial osteosynthesis with a plate and lateral avulsion repaired, (**c**, **d**), respectively

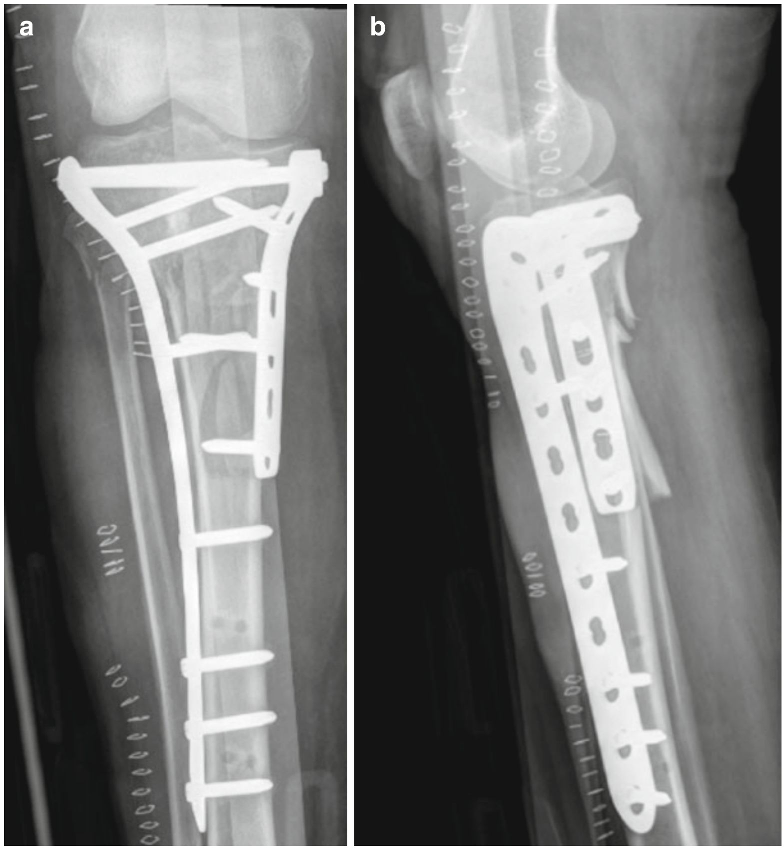

Fig. 8.6 Lateral and medial osteosynthesis plates for Schatzker VI fracture: AP view (**a**) and lateral view (**b**)

partments of the leg is mandatory, respectively. A sequential treatment will be more prudent. This, however, presents an opportunity to carry out early internal fixation. In level 1 trauma center with plastic surgeons, the open fractures can be treated with immediate fixation and early soft tissue coverage [9].

In fractures with suspected injury of the popliteal artery, an angio-CT must be performed. Arterial injury must be repaired immediately; but we must first stabilize the fracture with an external fixator. The artery can be repaired with a bypass using vein graft or prosthesis. It is very important to perform fasciotomy opening the four compartments of the leg after repair.

The repair of associated soft tissue injuries is determined on an individual basis. Meniscal injuries should be repaired whenever possible. Osseous avulsion of ligaments can be directly repaired with sutures or screws. Further ligament reconstructions are best delayed until bone healing has occurred, knee range of motion has returned [11], and hardware has been removed.

8.6 Postoperative Treatment

The patients with closed fractures received intravenous antibiotics for a period of 24–48 h after the surgery. When the fixation is stable, the main goal is to emphasize early motion to avoid stiffness. We use a hinged knee brace only if there is subtle instability. During the first week the patient can do passive motion and then begin on active range of knee motion and isometric quadriceps strengthening. The patient is kept non-weight bearing until 6–12 weeks. During this time, the patient must walk with the help of crutches. Thereafter, weight bearing is advanced based on radiographic evidence of fracture healing.

Conclusions

Complex fractures of the proximal tibia are associated with soft tissue and neurovascular injuries. Appropriate clinical assessment, diagnostic imaging, and management of the soft tissue are the most important aspects. The sequential treatment algorithm with temporary external fixation allows the recovery of soft tissue and improvement of the results. Definitive treatment is aimed at reconstruction of the articular surfaces and restitution of normal mechanical axis. The use of the two-incision approach decreases wound complications and deep sepsis. Minimally invasive techniques and anatomically contoured plates have afforded more biological approaches to these fractures. Bilateral dual plating is usually recommended as the definite fixation for this kind of fracture but may need an additional plate to fix the posterior column.

References

1. Schatzker J, McBroom R, Bruce D (1979) The tibial plateau fracture. The Toronto experience 1968–1975. Clin Orthop Relat Res 138:94–104
2. Hohl M, Part I (1991) Fractures of the proximal tibia and fibula. In: Rockwood C, Green D, Bucholz R (eds) Fractures in adults, 3rd edn. JB Lippincott, Philadelphia, pp 1725–1761
3. Zhu Y, Yang G, Luo CF, Smith WR, Hu CF, Gao H, Zhong B, Zeng BF (2012) Computed tomography-based three-column classification in tibial plateau fractures: introduction of its utility and assessment of its reproducibility. J Trauma Acute Care Surg 73:731–737
4. Gustilo R, Mendoza R, Williams D (1984) Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 24:742
5. Tscherne H, Gotzen L (1984) Fractures with soft tissue injuries. Springer, Berlin
6. Andrews JR, Tedder JL, Godbout BP (1992) Bicondylar tibial plateau fracture complicated by compartment syndrome. Orthop Rev 21:317–319
7. Chan PS, Klimkiewicz JJ, Luchetti WT et al (1997) Impact of CT scan on treatment plan and fracture classification of tibial plateau fractures. J Orthop Trauma 11:484–489
8. Zura RD, Brownea JA, Blacka MD, Olson SA (2007) Current management of high-energy tibial plateau fractures. Curr Orthop 21:229–235
9. Rubio-Suarez JC (2013) Tibial plateau fractures. In: Rodríguez-Merchán EC (ed) Traumatic injuries of the knee. Springer, Milan, pp 15–28
10. Egol KA, Tejwani NC, Capla EL et al (2005) Staged management of high-energy proximal tibia fractures (OTA TYPES 41): the results of a prospective, standardized protocol. J Orthop Trauma 19:448–455
11. Berkson EM, Virkus WW (2006) High-energy tibial plateau fractures. J Am Acad Orthop Surg 14:20–31
12. Barei DP, Nork SE, Mills WJ, Henley MB, Benirschke SK (2004) Complications associated with internal fixation of high-energy bicondylar tibial plateau fractures utilizing a two-incision technique. J Orthop Trauma 18:649–657
13. Young MJ, Barrack RL (1994) Complications of internal fixation of tibial plateau fractures. Orthop Rev 23:149–154
14. Waddell JP, Johnston DW, Neidre A (1981) Fractures of the tibial plateau: a review of ninety-five patients and comparison of treatment methods. J Trauma 21:376–381
15. Luo CF, Sun H, Zhang B et al (2010) Three-column fixation for complex tibial plateau fractures. J Orthop Trauma 24:683–692
16. Marsh JL, Smith ST, Do TT (1995) External fixation and limited internal fixation for complex fractures of the tibial plateau. J Bone Joint Surg Am 77:661–673
17. Mikulak SA, Gold SM, Zinar DM (1998) Small wire external fixation of the high energy tibial plateau fractures. Clin Orthop Relat Res 356:230–238

9 Complex Fractures of Tibial Pilon

José Manuel Martínez-Díez

9.1 Introduction

The analysis of the fracture pattern must be performed with the three standard views of the ankle. Full-length tibia and fibula films can also offer information on general alignment [1, 2]. Ruëdi and Allgöwer [3] offered the original foundation for classification, indicating three fracture types that increase in severity, from low-energy non-displaced fractures of the tibial plafond to high-energy, to severely comminuted, and to impacted articular fracture patterns. Minimal improvements to classification agreement were observed with the development of the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) classification system. Although orthopedic surgeons might not necessarily agree on the specific classification of the pilon fracture pattern presented, there is reliably high agreement on assessing the severity of the injury and also in determining the quality of a poor or good reduction.

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9.2 Acute Management

Important considerations include the presence of an open wound and/or vascular injury [4]. A medical history involving diabetes or smoking can also be crucial to management decisions and potential avoidance of future wound complications. Patients with complicated diabetes have an increased risk for overall complications and an increased risk for revision surgery.

Comminution, Tscherne class of fracture, significant open wounds, and a fibular fracture serve the understanding of the amount of energy absorbed. A present fibular fracture typically is associated with higher-energy injuries. The presence of the fracture contributes only to the direction of the mechanism, typically occurring with valgus and axial load [5]. The absence of a fibular fracture or tension failure of the fibula is associated with a varus and axial load injury pattern [6].

After medical clearance and before definitive fixation, restoring the alignment is essential to allow for soft tissue stabilization. Acute fibular fixation provides restoration of length safely in the initial period without an increased risk for complications [2]. However, preoperative planning, including determination of the definitive surgical incision, is paramount. Classically, many surgeons have attested a minimum of a 7-cm skin bridge to minimize soft tissue and wound complications. If the surgeon is uncertain of the posterior incision, or is not the definitive treating surgeon, it might be prudent to defer fibular fixation until an external fixator has been placed to

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restore the general mechanical axis and length. Typically a delta frame construct with two 5-mm pins in the tibial shaft is the most common construct (Fig. 9.1).

9.3 Operative Timing

Definitive operative management within 6 h of injury may be safe, but when high-energy mechanisms are evaluated, ORIF that had been undertaken in the acute period yields suboptimal results and high complication rates [7, 8]. Inflammatory process is potentially at its highest for up to 6 days post injury. Tscherne emphasized the importance of soft tissue management [9]. His soft tissue classification system offers graded indicators of severe soft tissue damage, ranging from minimal superficial abrasions and degloving injuries to deep muscular and subcutaneous fat contusions, vascular injury, and compartment syndrome.

There are two safe surgical windows: an early period, within 6 h after injury, and a late period between 6 and 12 days after injury. A staged protocol consisting of acute external fixation and delayed definitive reconstruction yields better results, with lower complication rates and higher clinical outcomes [10]. Furthermore, the presence of blisters, which occur at a relatively high rate in pilon fractures, offers more clues to the awaiting definitive management. With blood-filled blisters Giordano recommended waiting for full reepithelialization before operative intervention [11]. Despite the success of the staged protocol, proponents for early ORIF still remain [12]. When planning for definitive fixation, CT scan is an invaluable tool for defining the articular fragments and for the purpose of the definitive surgical approach to perform (Fig. 9.2).

9.4 Definitive Treatment

The treatment algorithm, which places emphasis on restoration of length with fibular reconstruction, reconstruction of the metaphyseal shell and articular joint, bone grafting, and medial buttress to stabilize metaphysis for the diaphysis reconstruction, still applies. Classically, the standard approach to the tibial plafond is described as a 2-incision technique, an anteromedial incision for the tibia and a posterolateral incision for the fibula. Careful consideration must be made to avoid violating the tibial anterior tendon sheath (Fig. 9.3).

An anterolateral approach to the tibial plafond allows direct access to the Tillaux–Chaput fragment unlike the anteromedial approach. Identification and protection of superficial peroneal nerve branches are imperative. Alternatively, the direct anterior approach can offer access to both the anteromedial and the anterolateral fragments of a pilon fracture, with a straightforward linear incision centered over the tibiotalar joint (Fig. 9.4). Posterior approaches to the pilon are used in selected situations.

At the time of definitive open reduction and internal fixation, the surgical goals are the following: (1) anatomical articular reduction; (2) length, alignment, and rotation of the reconstructed articular block adequately assembled to the shaft; (3) metaphyseal defects must be improved by reducing impacted articular segments and supported with bone graft.

Atraumatic surgical technique and meticulous soft tissue handling are paramount in minimizing potential wound complications. Limited periosteal stripping will decrease the chances of further devascularizing involved bone segments.

The individual articular fragments must be reduced from posterior to anterior, typically using the posterolateral articular fragment, with its ligamentous attachments to the fibula. The provisional reduction of each fragment must be secured with at least two Kirschner wires.

Precise restoration of articular congruity should allow the articular block to correctly "key" into the adjacent metaphyseal and diaphyseal fragments, thereby restoring columnar length, rotation, and overall alignment.

A low-profile anterior or anterolateral plate must be then placed to buttress the tibial

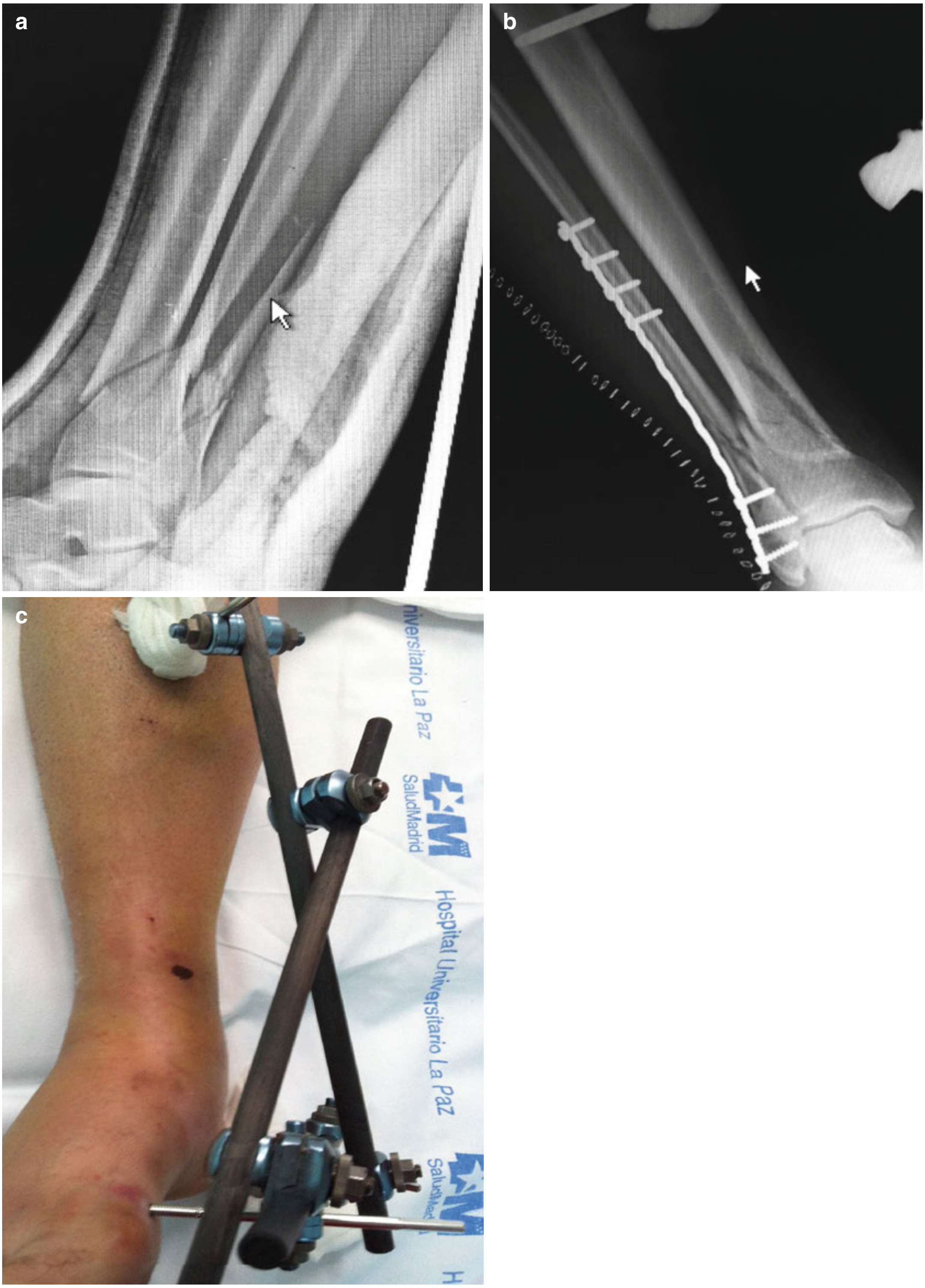

Fig. 9.1 Closed extra-articular distal tibial and fibular fracture treated by means of (**a**) ORIF (open reduction and internal fixation) of fibular fracture and (**b**) provisional external fixator of tibial fracture. (**c**) Clinical view of the delta frame construct

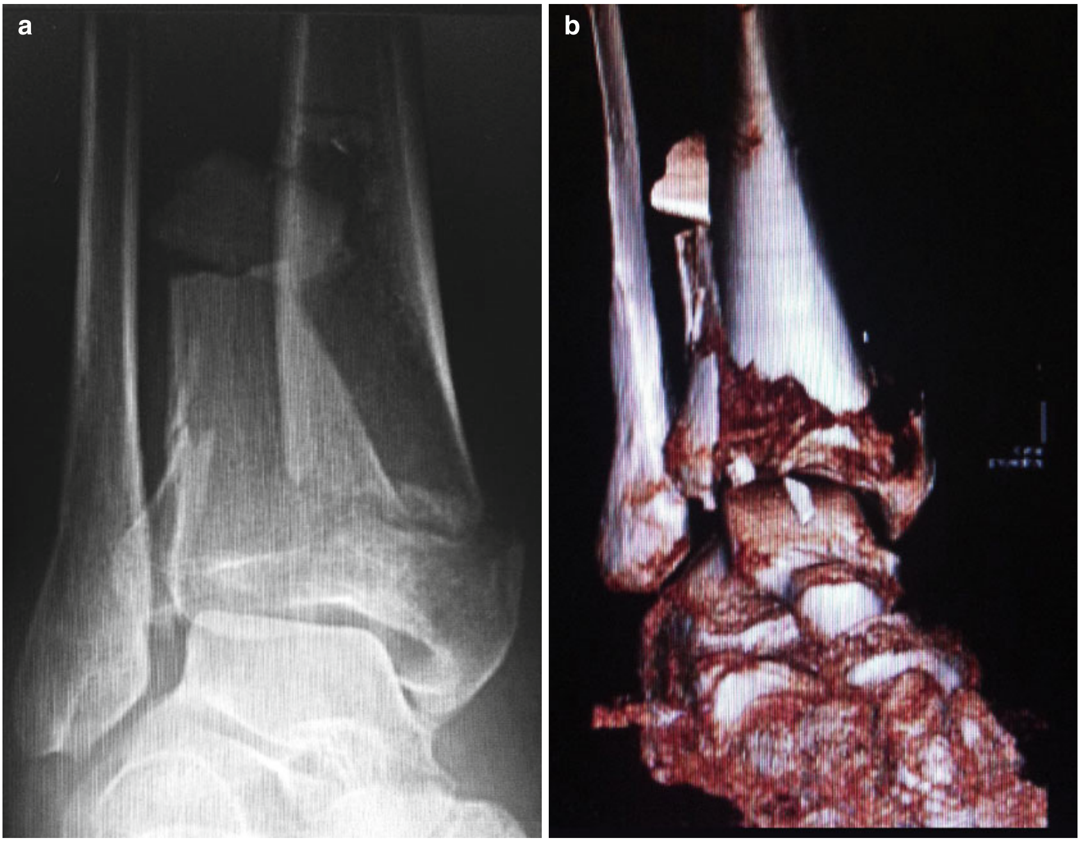

Fig. 9.2 Anteroposterior radiograph of an intra-articular pilon fracture (**a**) and CT scan better defining the articular fragments (**b**)

Fig. 9.3 Classic anteromedial approach to a distal tibial fracture

metaphysis and link the articular block to the tibial diaphysis while minimizing soft tissue tension at closure (Fig. 9.5). A supplemental medial bridge plate may be added in instances of significant metaphyseal comminution or bone loss (Fig. 9.6). Early aggressive range of motion therapy is initiated once the incisions have adequately healed, although weight bearing must not be allowed for 10–12 weeks postoperatively.

We believe that fractures without soft tissue damage allow the application of a minimally invasive internal fixation in the first 12–24 h, aiming for anatomical reduction (Fig. 9.7). Tscherne type 3 and open fractures dictate a two-step approach: temporary bridging external fixation, later substituted by an internal biological osteosynthesis or by a definitive external fixation (using mostly a circular frame spanning or not the ankle joint). The choice of implant should be based on the status of the soft tissues and the surgeon's preference.

Fig. 9.4 Direct anterior approach offers access to anteromedial and anterolateral fragments

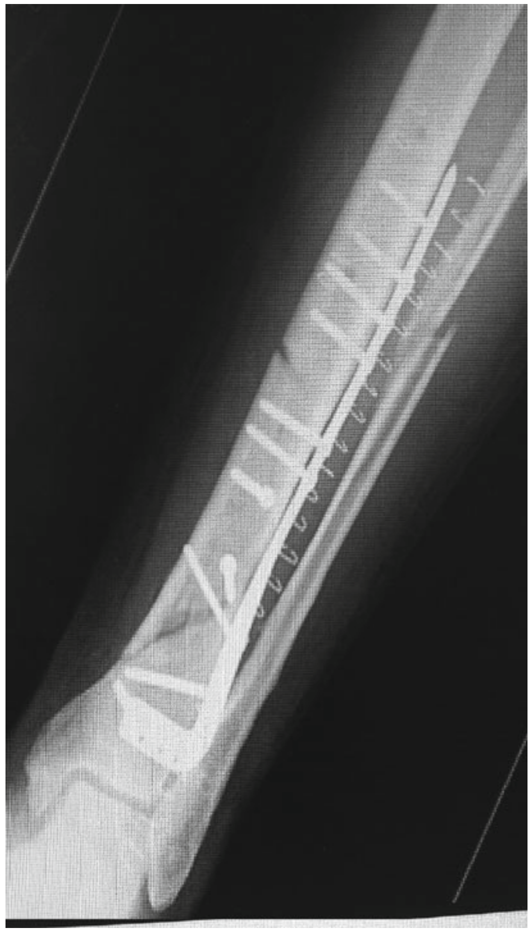

Fig. 9.5 Low-profile anterolateral plate used in a multifragmentary distal tibial fracture

9.5 Complications

There are many potential complications resulting from the surgical treatment of tibial pilon fractures.

9.5.1 Early Complications

Wound complications: In the early postoperative period, the most common wound complication is superficial surgical wound necrosis without dehiscence. It can be treated with standard local wound care. If associated with wound erythema, there may be a role for systemic oral antibiotics. If a surgical wound dehiscence is identified, the patient should be treated with urgent surgical debridement. Deep wound infection also requires surgical treatment. Definitive soft tissue management with rotational or free tissue transfer may be needed; a surgeon familiar with such procedures should be consulted early in the treatment process to appropriately coordinate the reconstruction.

9.5.2 Late Complications

Chronic infection: Late or chronic infections after pilon fracture surgery are generally associated with osteomyelitis and contaminated surgical implants. The implants usually cannot be retained. All devitalized and necrotic bone should be removed. Large bony defects may be filled with an antibiotic-impregnated cement spacer.

Malunion: Malunion or nonunion after pilon fracture surgery may pose complex reconstructive problems. Often, the articular surface of the pilon

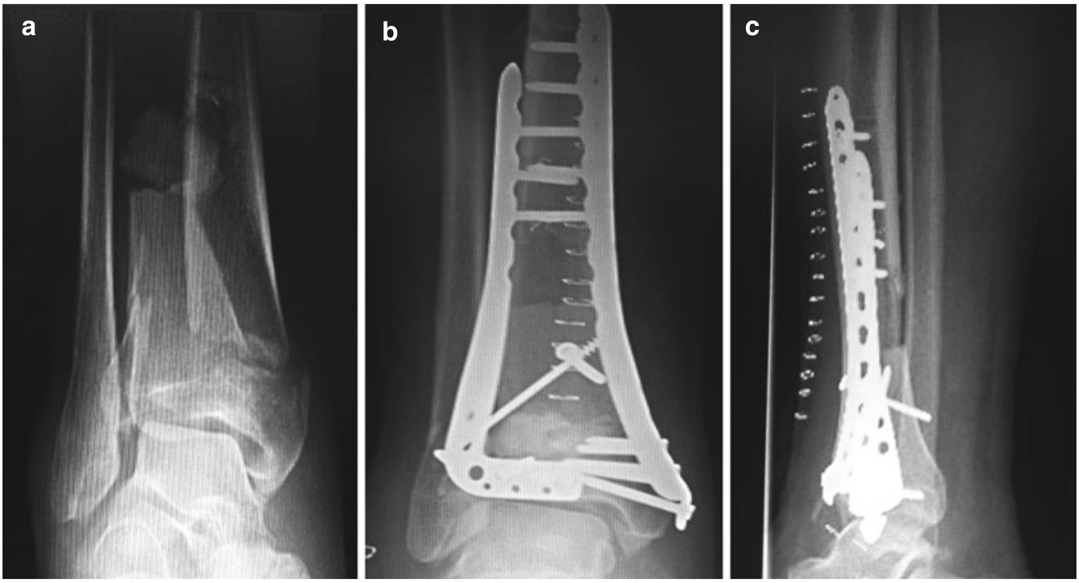

Fig. 9.6 Four-fragment pilon fracture in a 48-year-old patient (**a**). ORIF (open reduction and internal fixation) with an anterolateral plate and a supplemental medial bridge plate. Anteroposterior view (**b**). Lateral view (**c**)

Fig. 9.7 MIPO (minimally invasive plate osteosynthesis) of a distal tibial fracture after 2 weeks of external fixator (**a**). No signs of skin necrosis and infection after the MIPO technique (**b**)

fracture has united, and the nonunion or malunion is largely extra-articular. If the articular surface is well aligned, an extra-articular correction of the deformity or nonunion may be performed. The selection of nail fixation, plate fixation, or external fixation should be made depending on the distance of the deformity from the articular surface. Large complex deformities, particularly in compromised soft tissues, may be best treated with gradual correction and distraction osteogenesis. The treatment of intra-articular malunion or nonunion requires a careful assessment of the viability of the ankle joint. Staging arthroscopy may be used to evaluate the chondral surface in circumstances where other diagnostic imaging studies have failed to provide sufficient information for surgical planning and decision making. The treatment of intra-articular nonunion or malunion after pilon fracture is generally reserved for partial articular fractures.

The most common long-term complication after a tibial pilon fracture is posttraumatic arthritis. Radiographic findings of posttraumatic arthritis may not always correlate with the patient's symptoms or reported disability. The most reliable treatment of end-stage posttraumatic ankle arthritis is arthrodesis. Short- and intermediate-term outcomes are generally good after arthrodesis, with patients reporting a significant reduction in pain and improvement in gait.

Conclusions

"Pilon" or "plafond" fracture pattern is defined by the intra-articular involvement of the distal tibia with metaphyseal extension. It only occurs in a small percentage of tibia and lower extremity injuries. One third of pilon fractures stem from high-energy mechanisms of injury and they are often associated with concomitant polytrauma. Historically, treatment involving early acute open reduction and internal fixation (ORIF) led to clinical outcomes with high complication rates. The implementation of a delayed and staged surgical treatment protocol, along with the improvements in imaging, implant technology, and surgical techniques, has allowed us to decrease the complication rates. Some recent authors have suggested that early definitive ORIF can have comparable results with staged protocols.

References

1. Teeny SM, Wiss DA (1993) Open reduction and internal fixation of tibial plafond fractures. Variables contributing to poor results and complications. Clin Orthop Relat Res 292:108–117
2. Sirkin M, Sanders R, DiPasquale T et al (1999) A staged protocol for soft tissue management in the treatment of complex pilon fractures. J Orthop Trauma 13:78–84
3. Ruëdi TP, Allgöwer M (1979) The operative treatment of intra-articular fractures of the lower end of the tibia. Clin Orthop Relat Res 138:105–110
4. Patterson MJ, Cole JD (1999) Two-staged delayed open reduction and internal fixation of severe pilon fractures. J Orthop Trauma 13:85–91
5. Bourne RB, Rorabeck CH, Macnab J (1983) Intra-articular fractures of the distal tibia: the pilon fracture. J Trauma 23:591–596
6. Barei DP, Nork SE, Bellabarba C et al (2006) Is the absence of an ipsilateral fibular fracture predictive of increased radiographic tibial pilon fracture severity? J Orthop Trauma 20:6–10
7. Bonar SK, Marsh JL (1994) Tibial plafond fractures: changing principles of treatment. J Am Acad Orthop Surg 2:297–305
8. Mast JW, Spiegel PG, Pappas JN (1988) Fractures of the tibial pilon. Clin Orthop Relat Res 230:68–82
9. Tscherne H, Schatzker J (1993) Major fractures of the pilon, the talus, and the calcaneus. Springer, Heidelberg
10. Mehta S, Gardner MJ, Barei DP et al (2011) Reduction strategies through the anterolateral exposure for fixation of type B and C pilon fractures. J Orthop Trauma 25:116–122
11. Giordano CP, Koval KJ (1995) Treatment of fracture blisters: a prospective study of 53 cases. J Orthop Trauma 9:171–176
12. White TO, Guy P, Cooke CJ et al (2010) The results of early primary open reduction and internal fixation for treatment of OTA 43. C-type tibial pilon fractures: a cohort study. J Orthop Trauma 24:757–763

Complex Fractures of the Calcaneus

10

Eduardo García-Rey

10.1 Introduction

Fractures of the calcaneus are the most frequent injuries in the tarsal region, and their prognosis is relatively poor [1]. The bone anatomy and the surrounding soft tissues are some of the reasons for the difficulty of the management of these fractures. Modern imaging techniques and different surgical approaches have been developed over the last years to improve the results of these injuries [2]. This chapter tries to summarise most important points.

10.2 Bone Anatomy and Mechanism of Injury

The function of the calcaneus is to provide vertical support during weight-bearing and to anchor calf musculature. The complex anatomy of the superior surface and its relationship to the inferior aspect of the talus provide the proper inversion and eversion of the foot during walking [3].

A fall from a height is the most frequent mechanism for this fracture. The axial loading over the talus fractures the calcaneus, and the different types of intra-articular patterns can be observed depending on the landing position of the foot. The so-called separation fracture or primary fracture line appears in the sinus tarsi and extends from the posterior facet to the medial wall and to the angle of Gissane anterolaterally, creating two important identifiable fragments: the posterolateral and the anteromedial segments [4, 5]. Although the comminution of this fracture is very frequent, the orientation of the secondary fracture line originates the two most common fractures patterns: the tongue-type fragment, which is oriented transversely, exiting posteriorly towards the tuberosity, and the joint depression type, in which the secondary fracture line exits on the superior aspect of the tuberosity [6, 7].

10.3 Classification and Radiological Evaluation

During the last decades, progress in diagnostic imaging tools has helped to dilucidate the morphology of this complex fracture. Modern computed tomography (CT) allows us to visualise these injuries in detail and to establish a proper prognosis. A complete radiological assessment with plain radiographs must be done if this fracture is suspected including foot dorsoplantar, anterior and oblique, lateral and axial views. These four plain radiographs can reveal the differences between the tongue-type and the joint depression fractures as well as the displacement of the lateral wall. Bohler's angle can be assessed on the lateral view, providing an initial impression of the characteristics of the lesion (Fig. 10.1). Although classification is not easy to perform here, the distinction between extra-articular and intra-articular can be

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Fig. 10.1 Lateral view of an ankle radiograph of a 28-year-old male patient after fall from a height

Fig. 10.2 Axial computed tomography of the same patient

made at this point. An overall viewing of the lesion as displaced or not and the extension of the fracture to the posterior facet can also be observed. However, a complete description of the fracture, particularly for an intra-articular lesion that may be operated, can be only assessed by CT study. Sanders et al. described the characteristics of the intra-articular subtalar displacement based on the pattern of the fracture and the posterior facet in the coronal view [8]. Type I is described as non-displaced, type II as a two-part fracture, type III as a three-part fracture and type IV as severely comminuted fractures; the other subtypes depend on the fracture line in relation to the posterior facet and the subtalar joint. This classification is used very frequently; however, some authors report difficulties in obtaining good reliability for this issue yet [9, 10]. CT studies provide adequate reconstruction to evaluate all fragments on every view, particularly the axial view, which reveals the secondary fracture line (Fig. 10.2).

10.4 Management

A patient injured after a fall from a height usually reports much pain and may have some severe lesions. Particular attention must be paid to the spine, both knees and both hindfeet. Once the fracture is diagnosed with plain radiographs as mentioned above, the physician must decrease pain and swelling. Severe complications related to soft tissues like compartmental syndromes and open fractures may occur. Elevation and immobilisation can initially control these problems; however, compression and early motion are indicated after a few days when conservative treatment is the final decision.

Initial plain radiographs should be enough to select which fractures require surgery or not, and a CT scan is necessary only if surgery is finally indicated [11]. The long-term results for conservative treatment are not so poor as the degree of displacement may suggest, although some residual symptoms can be disabling for some patients [12]. On the other hand, a better anatomical reconstruction of the calcaneus has shown better clinical results at long term; thus, the complications observed secondary to an open reduction and internal fixation (ORIF) of these fractures did not affect the clinical outcome [13] (Fig. 10.3). Although the decision for surgery is not easy to take, it seems that surgery would be indicated for displaced fractures: a decrease of Bohler's angle with widening and flattening of the heel and displacement of >1 cm or angulation of >10° of the tuberosity fragment [14]. Recently, Rammelt et al. have reported that although the severity of the fracture is related to the long-term result, an anatomical reconstruction improves the final result [15].

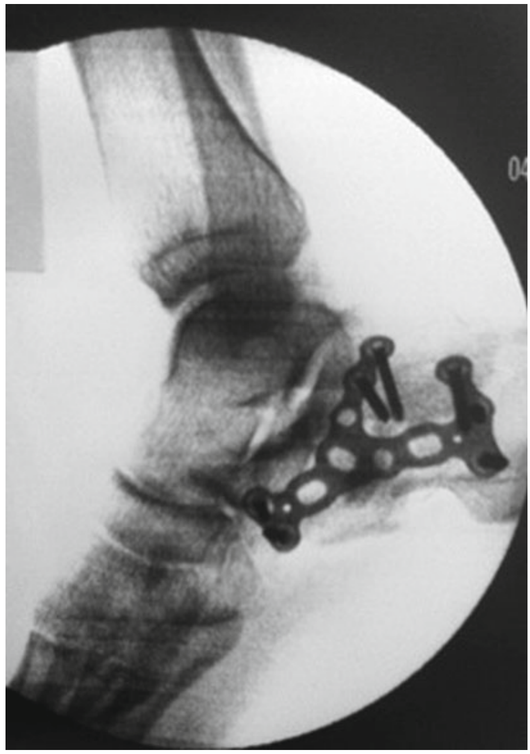

Fig. 10.3 Intraoperative radiographic view of reduction of the fracture from the same patient

Table 10.1 tries to summarise this controversial topic. Although conservative treatment avoids wound complications derived from surgery, clinical outcome seems to be related to a better reconstruction of the subtalar joint. Parmar et al. reported similar results for both treatments at 1 year [16]; nevertheless, Rodríguez-Merchán and Galindo observed better results with operative treatment in a comparative clinical and radiological study although they emphasised the importance of good surgical technique and adequate reduction [17]. In the same manner, Thordarson and Krieger reported better clinical outcome and a better range of motion after surgery in a prospective randomised trial [18]. Buckley et al. observed similar results for both operative and nonoperative treatments in a large multicentre study; however, they highlighted some factors like worker's compensation and whether female patients are prone to be treated surgically, finding that the severity and the reduction of the fracture also influenced the final clinical outcome [19]. Last but not least, Agren et al. observed similar results for both operative and nonoperative treatment at 1 year but also noted that surgery had some long-term benefits and less incidence for post-traumatic osteoarthritis [20].

Once the operative decision has been taken, the best surgical technique must be followed. Again, there is controversy between a limited or extended lateral L-shaped approach ORIF. In a comparative study, Weber et al. reported similar clinical outcomes and shorter operations including less wound complications for the percutaneous group than the ORIF group [21]; however, the extended lateral approach did not affect the long-term results as already mentioned above [22]. This percutaneous technique also provides a good result

Table 10.1 Some comparative studies for nonoperative and operative treatment for displaced calcaneal fractures

Authors	Type of study	Conservative/ operative	Follow-up	Results and discussion
Parmar et al. [16]	Prospective randomised	31/25	1 year	Similar outcome
Thordarson and Krieger [18]	Prospective randomised	11/15	17 months	Better result for operative treatment
Rodríguez-Merchán and Galindo [17]	Retrospective	30/28	4 (2–9 years)	Depends on surgical technique
Buckley et al. [19]	Prospective randomised controlled multicenter	148/161	2–8 years	Similar outcome but worker's compensation, women. Importance for quality of reduction
Agren et al. [20]	Prospective randomised controlled multicenter	27/31	10 years (8–12)	Better long-term results for surgery, but no need for subtalar fusion increased for conservative treatment

evaluated either arthroscopically or with newer radiological intraoperative imaging in moderate displaced fractures [23]. For severely comminuted fractures, a primary subtalar arthrodesis could be indicated associated to an osteosynthesis of the fracture [24]. Finally, when conservative treatment for post-traumatic subtalar osteoarthritis fails, a subtalar fusion can be performed with acceptable results.

Conclusions

Current evidence supports the surgical treatment for displaced intra-articular fractures of the calcaneus; it provides a better anatomical reconstruction of the subtalar joint and a recovery of the Bohler's angle, which is related to a better prognosis for the lesion. The choice between a limited and an extended lateral ORIF should be taken according to the experience of the team. Subtalar fusion continues to provide an adequate result for post-traumatic osteoarthritis or very comminuted fractures.

References

1. Cave EF (1963) Fracture of the os calcis – the problem in general. Clin Orthop Relat Res 30:64–66
2. Randle JA, Kreder HJ, Stephen D, Williams J, Jaglai S, Hu R (2000) Should calcaneal fractures be treated surgically? A meta-analysis. Clin Orthop Relat Res 377:217–227
3. Wagner UA, Sangeorzan BJ, Harrington RM (1992) Contact characteristics of the subtalar joint: load distribution between the anterior and posterior facets. J Orthop Res 10:535–543
4. Bohler L (1931) Diagnosis, pathology, and treatment of the fracture of the calcaneus. J Bone Joint Surg Am 13:75–89
5. Burdeaux BD (1983) Reduction of calcaneal fractures by the McReynolds medial approach technique and its experimental basis. Clin Orthop Relat Res 177: 87–103
6. Essex-Lopresti P (1952) The mechanism, reduction technique, and results in fractures of the os calcis. Br J Surg 39:395–419
7. Barei DP, Bellabarba C, Sangeorzan BJ, Benirschke SK (2002) Fractures of the calcaneus. Orthop Clin North Am 33:263–285
8. Sanders R, Fortin P, Di Pasquale T (1993) Operative treatment in 120 displaced intraarticular calcaneal fractures: results using a prognostic computed tomography scan classification. Clin Orthop Relat Res 290:87–95
9. Humphrey CA, Dirschl DR, Ellis TJ (2005) Interobserver reliability of a CT-based fracture classification system. J Orthop Trauma 19:616–622
10. Sayed-Noor AS, Agren PH, Wertenberg P (2011) Interobserver reliability and intraobserver reproducibility of three radiological classification systems for intra-articular calcaneal fractures. Foot Ankle Int 32:861–869
11. Kumar V, Hameed A, Bhattacharya R, McMuctry I (2006) Role of computerised tomography in management of intra-articular fractures of the os calcis. Int Orthop 30:110–112
12. Pozo JL, Kirwan EO, Jackson AM (1984) The long-term results of conservative management of severely displaced fractures of the calcaneus. J Bone Joint Surg Br 66:386–390
13. De Groot R, Frima AJ, Schepers T, Roerdink WH (2013) Complications following the extended lateral

approach for calcaneal fractures do not influence mid- to long-term outcome. Injury 44:1596–1600
14. Makki D, Anajjar HM, Walkay S, Ramkumar U, Watson AJ, Allen PW (2010) Osteosynthesis of displaced intra-articular fractures of the calcaneum. A long-term review of 47 cases. J Bone Joint Surg Br 92-B:693–700
15. Rammelt S, Zwipp H, Schneiders W, Dürr C (2013) Severity of injury predicts subsequent function in surgically treated displaced intraarticular calcaneal fractures. Clin Orthop Relat Res 471:2885–2898
16. Parmar HV, Triffit PD, Gregg PJ (1993) Intra-articular fractures of the calcaneum treated operatively or conservatively: a prospective study. J Bone Joint Surg Br 75-B:932–937
17. Rodríguez-Merchán EC, Galindo E (1999) Intra-articular displaced fractures of the calcaneus. Operative vs non-operative treatment. Int Orthop 23:63–65
18. Thordarson DB, Krieger LE (1996) Operative vs. nonoperative treatment of intra-articular fractures of the calcaneus: a prospective randomized trial. Foot Ankle Int 17:2–9
19. Buckley R, Tough S, Mc Comrmarck R, Pate G, Leighton R, Petrie D, Galpin R (2002) Operative treatment compared with nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am 84-A:1733–1744
20. Agren PH, Wretenberg P, Sayed-Noor AS (2013) Operative versus nonoperative treatment of displaced intra-articular calcaneal fractures. J Bone Joint Surg Am 95:1351–1357
21. Weber M, Lehmann O, Sägesser D, Krause F (2008) Limited open reduction and internal fixation of displaced intra-articular fractures of the calcaneum. J Bone Joint Surg Br 90-B:1608–1616
22. Rammelt S, Amlang M, Barthel S, Gavlik JM, Zwipp H (2010) Percutaneous treatment of less severe intraarticular calcaneal fractures. Clin Orthop Relat Res 468:983–990
23. Huefner T, Thermann H, Geerling J, Pape HC, Pohlemann T (2001) Primary subtalar arthrodesis of calcaneal fractures. Foot Ankle Int 22:9–14
24. Radnay CS, Clare MP, Sanders RW (2009) Subtalar fusion after displaced intra-articular calcaneal fractures: does initial operative treatment matter? J Bone Joint Surg Am 91-A:541–544

11 Complex Open Fractures

Aitor Ibarzábal-Gil

11.1 Introduction

In our clinical practice the best way to deal with the treatment of an open fracture and fully understand the pathology we face is to consider this situation as a soft tissue injury with a broken bone in. However, despite improvements in technology and surgical techniques, the rates of infection and nonunion are still troublesome. We must recognize in a short period of time the full extension of the lesion, the patient's general condition, and whether there are associated injuries that may delay or change the management of the fracture.

Protocols and algorithms are critical in these situations because the prognosis and treatment outcome of an open fracture greatly depends on the initial management of the same.

In this chapter we will try to review the general treatment of an open fracture, establish the level of evidence regarding the different possibilities of action, and propose a protocol that has been useful in focusing their treatment for our practice.

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11.2 History and Classification Systems

The first medical document written, the Smith papyrus, reveals that the ancient Egyptians treated open fractures by immobilization of the limb and animal tissue coverage [1].

Throughout history surgeons such as Ambroise Pare improved techniques for immobilization and debridement of these injuries with an emphasis on the treatment of soft tissue.

Still, we must bear in mind that until the advent of the antibiotic era, mortality of open fractures amounted to one third of patients, as Billroth communicates in the nineteenth century with 36 deaths of 93 open fractures of the lower limb.

The improvement in aseptic technique, anesthesia, and surgical techniques of fixation and the advent of antibiotics lead to a drastic reduction in mortality of open fractures and enable the preservation of the affected limb, reducing the rate of amputations that still amounted to 15 % of these fractures 40 years ago.

There are several classification systems of open fractures. The best known and more widely used is the Gustilo classification that proposed three main types depending on the state of the soft tissues [2–4] (Table 11.1). Gustilo published infection and amputation rates for each subgroup that varied between 0 % of amputations in types I,

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Table 11.1 Gustilo open fracture classification

Gustilo grade	Definition
I	Open fracture, clean wound, and wound <1 cm in length
II	Open fracture, wound >1 cm in length without extensive soft tissue damage, flaps, and avulsions
III	Open fracture with extensive soft tissue laceration, damage, or loss or an open segmental fracture. This type also includes open fractures caused by farm injuries, fractures requiring vascular repair, or fractures that have been open for 8 h prior to treatment
IIIA	Type III fracture with adequate periosteal coverage of the fracture bone despite the extensive soft tissue laceration or damage
IIIB	Type III fracture with extensive soft tissue loss and periosteal stripping and bone damage. Usually associated with massive contamination. Will often need further soft tissue coverage procedure (i.e., free or rotational flap)
IIIC	Type III fracture associated with an arterial injury requiring repair, irrespective of degree of soft tissue injury

Reproduced with permission from Gustilo et al. [3]

Table 11.2 AO-ASIF classification for soft tissues

Skin lesions IC (closed fractures)		Skin lesions IO (open fractures)	
IC 1	No skin lesion	IO 1	Skin breakage from inside out
IC 2	No skin laceration, but with contusion	IO 2	Skin breakage from outside in <5 cm, contused edges
IC 3	Circumscribed degloving	IO 3	Skin breakage from outside in >5 cm, increased contusion, devitalized edges
IC 4	Extensive, closed degloving	IO 4	Considerable, full-thickness contusion, abrasion, extensive open degloving, skin loss
IC 5	Necrosis from contusion		

Reproduced with permission from Müller et al. [7]

II, and IIIA and 16 % in type IIIB and over 40 % in type IIIC.

We must remember that in the Gustilo classification, the most accepted and used, the staging must be performed once explored in the operating room and completed the soft tissue debridement.

Tscherne proposed the Hannover open fracture score in which fractures are classified into four groups depending on the type of fracture, soft tissue injury, neurovascular status, ischemia time, and degree of contamination [5, 6].

AO-ASIF group proposed an interesting alternative that classifies the quality of the soft tissues in any type of fracture, and established two main subgroups, integument open and integument close, with five subtypes varying from intact soft tissues to massive lost necrosis and contamination. The classification is completed with two subgroups that indicate the level of muscular and neurovascular injury [7] (Table 11.2).

11.3 Treatment

11.3.1 Initial Management

Treatment should begin with a quick and complete approach to the patient, especially in the case of polytrauma, allowing us to set priorities. In most centers protocols to discard potentially vital injury at the time of the reception are used routinely [8–16].

We must proceed to establish prophylactic antibiotics, immobilize the limb with splints for preliminary radiographic study, and prepare the operating room.

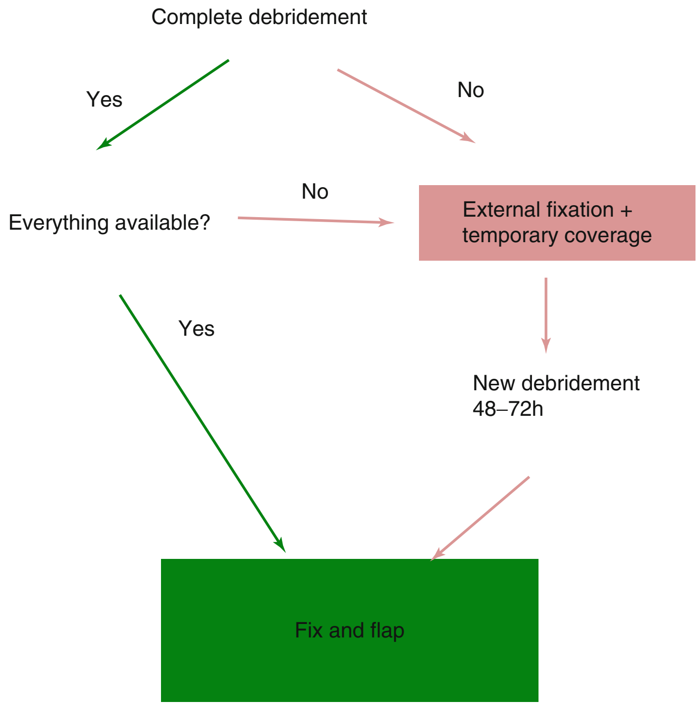
Prophylaxis and treatment for tetanus should be considered for every patient with an open fracture.

There is no general agreement on which antibiotic to use, but several reports have found statements with great level of evidence.

These are level 1 recommendations:

- Systemic antibiotic coverage directed at gram-positive organisms should be initiated as soon as possible after injury; additional gram-negative coverage should be added for type III fractures.
- High-dose penicillin should be added in the presence of fecal or potential clostridial contamination (e.g., farm-related injuries).

Fig. 11.1 Algorithm for treatment of open fractures



- Fluoroquinolones offer no advantage compared with cephalosporin/aminoglycoside regimens, result in higher infection rates in type III open fractures, and have a detrimental effect on fracture healing.

  Recommendations with level 2 of evidence are:
- In type III open fractures, antibiotics should be continued for 72 h after injury and less than 24 h after soft tissue coverage has been achieved.
- Once-daily aminoglycoside dosing is safe and effective for type II and III fractures.

We use routinely intravenous infusion of cefazolin 1 g every 8 h in Gustilo type I fractures, and we add tobramycin 300 mg every 24 h plus clindamycin 600 mg every 8 h in Gustilo type II and type III fractures until definitive coverage is achieved. We do not use routinely high-dose penicillin in our center for farm injuries, and fecal-contaminated injuries are uncommon.

Once in the operating room, we will proceed to the thorough irrigation of the wound with saline and chlorhexidine solution. Higher-pressure devices should not be used because of their association with added soft tissues and bone damage. Early cultures of the wound have not proven useful in current clinical practice. Level I evidence study found that there is no significant difference between antibiotic and liquid soap solutions in wound infection or bone-healing rates in the management of open fractures.

11.3.2 Debridement and Fixation

Each fracture could conceivably be treated quite differently, ranging from external fixation and delayed closure or fixation to immediate irrigation, debridement, and primary closure. The status of the soft tissues surrounding the fracture site is of paramount importance in this decision-making process, which usually influences the initial management. The viability of the limb must be assessed by the team. Once preservation of the limb is accorded, next step must be taken depending on the multiple situations according to the algorithm proposed (Fig. 11.1).

The three main principles for limb salvage surgery are debridement, stable fixation, and early coverage [8–16].

The initial debridement should include a sequential evaluation of skin, fat, fascia, muscle, and bone. The propensity to excise as little as possible should be avoided. Our approach with open fracture is to remove any devitalized tissue (including bone) at the initial debridement. Only large articular fragments can be preserved in order to achieve joint reconstruction. If a second debridement is needed, some questionable muscle may be left until the next scheduled debridement. Ideally, coverage of the open fracture should take place after one to two formal debridements with 48 h between them.

Early stabilization of open fractures provides many benefits to the injured patient. It protects the soft tissues around the zone of injury by preventing further damage from mobile fracture fragments. It also restores length, alignment, and rotation—all vital principles of fracture fixation. This restoration of length also helps decrease soft tissue dead spaces and has been shown in studies to decrease the rates of infection in open fractures.

Skeletal traction and external fixation are the quickest fixation constructs to employ. The use of skeletal traction should be reserved only for selected open fracture types (i.e., pelvis fractures in addition to external fixation and very proximal femur fractures), and if used, it should only be for a short selected time.

External fixation is the treatment of choice in most open fracture as initial stabilization of the bone. It provides excellent management of the fracture and is a safe and fast method, and its flexibility allows its use in almost all types of fracture. External fixation is placed as a spanning construct leaving the zone of injury free of pins and easily accessible for imaging studies, second debridements, and future fixation. The surgeon should also be cognizant of future incision placement and avoid placing external fixation pins in these areas.

Definitive fixation must be focused only on the fracture pattern with independence of the tissue coverage technique used. Plate fixation is generally indicated for open upper extremity fractures and periarticular fractures where reconstruction of the articular surface is paramount. Plates may be also indicated in isolated cases of diaphyseal comminution with questionable vascularized fragments as an alternative to radical debridement in order to avoid great bone defects. Cases are mandatory to provide definitive coverage that will provide additional vascularization to the fracture site (Fig. 11.2).

In diaphyseal fractures we will use intramedullary nails. A report called SPRINT (Study Prospectively evaluate Reamed Intramedullary Nails in Tibial fractures) enrolled more than 1,300 patients and randomized them to reamed or non-reamed tibial nails. There were 400 open fractures enrolled in the study, and the major end point was reoperation. They found a 27 % risk of revision in open fractures, regardless of the treatment used. Although not statistically significant, a trend was noted toward the need for revision of surgery SPRINT ($P = 0.16$) when reamed nails were used in open fractures. There are no differences in infection rates or compartment syndrome between reamed and non-reamed nailing in tibial open fractures.

Conversion from external fixation to an intramedullary nail is safe given two parameters: conversion in less than 2 weeks and absence of pin site infections. Conversion after pin site infections may require additional time and antibiotic treatment after removing the external fixator and placement of the intramedullary nail.

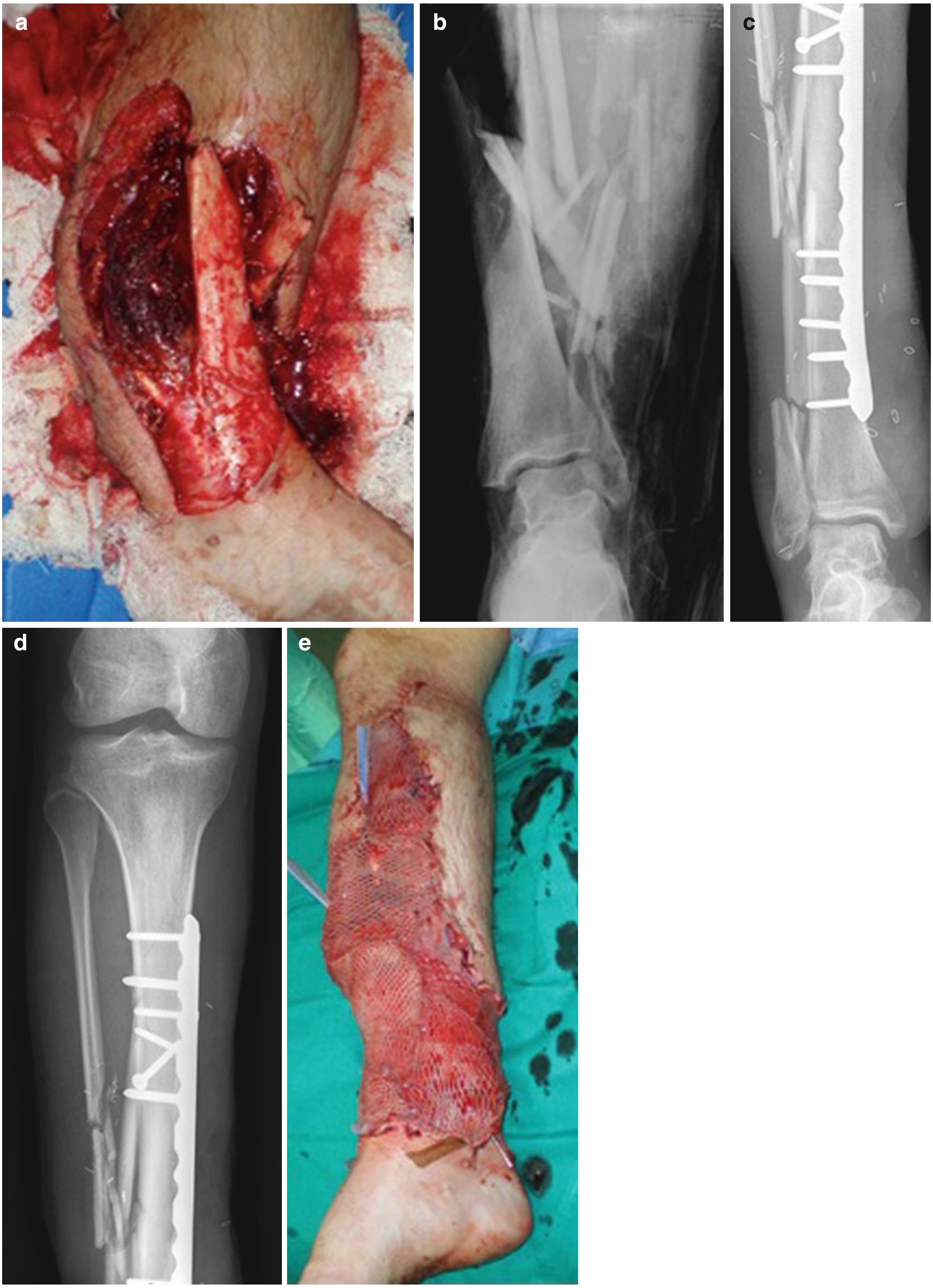


Fig. 11.2 Immediate debridement and coverage of open tibial fracture Gustilo type IIIB with plate fixation and free vascularized flap of the latissimus dorsi in the first 8 h: (**a**) clinical view of the open fracture, (**b**) anteroposterior radiograph of fracture, (**c**, **d**) radiographs after bone fixation. (**e**) Clinical view after the free vascularized flap of the latissimus dorsi

Conclusions

The coordination of multidisciplinary specific units to combine polytrauma cases and catastrophic members is critical in optimizing the resources of a region, establishing protocols, and having all the possibilities for reconstructive surgery to successfully confront the growing number of complex open fractures. Debridement can be completed in a one-stage procedure with definitive fixation or by several consecutive debridements with external fixation meanwhile. Though definitive treatment of open fractures depends on several issues as the general status of the patient and the availability of adequate human and material resources, the onset of antibiotic perfusion and debridement must be immediate. Definitive treatment should be planned and agreed by the multidisciplinary team; once coverage is planned, adequate and definitive fixation must be performed, according to the "fix and flap" principles. We must keep in mind that amputation is a reasonable treatment option when our best expectations for conservative treatment are worse than those with a prosthetic limb.

References

1. Pape HC, Webb LX (2008) History of open wound and fracture treatment. J Orthop Trauma 22(10 Suppl):S133–S134
2. Gustilo RB, Anderson JT (1976) Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am 58:453–458
3. Gustilo RB, Mendoza RM, Williams DN (1984) Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 24:742–746
4. Gustilo RB, Gruninger RP, Davis T (1987) Classification of type III (severe) open fractures relative to treatment and results. Orthopedics 10:1781–1788
5. Tscherne H, Oestern HJ (1982) A new classification of soft-tissue damage in open and closed fractures. Unfallheilkunde 85:111–115
6. Tscherne H, Gotzen L (1984) Fractures with soft tissue injuries. Springer, Berlin/New York
7. Müller ME, Nazarian S, Koch P, Schatzker J (1990) The comprehensive classification of fractures of long bones. Springer, Berlin, pp 116–147
8. Crowley DJ, Kanakaris NK, Giannoudis PV (2007) Debridement and wound closure of open fractures: the impact of the time factor on infection rates. Injury 38:879–889
9. Parrett BM, Matros E, Pribaz JJ, Orgill DP (2006) Lower extremity trauma: trends in the management of soft-tissue reconstruction of open tibia-fibula fractures. Plast Reconstr Surg 117:1315–1319
10. Bhandari M (2008) Reamed versus non-reamed tibial intramedullary nail insertion on re-operation rates. In: 75th annual meeting of the American Academy of Orthopaedic Surgeons, San Francisco, Mar 2008
11. Bhandari M, Guyatt GH, Swiontkowski MF, Schemitsch EH (2001) Treatment of open fractures of the shaft of the tibia. J Bone Joint Surg Br 83:62–68
12. Hertel R, Lambert SM, Muller S, Ballmer FT, Ganz R (1999) On the timing of soft-tissue reconstruction for open fractures of the lower leg. Arch Orthop Trauma Surg 119:7–12
13. Godina M (1986) Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg 78:285–292
14. Herscovici D Jr, Sanders RW, Scaduto JM, Infante A, Di Pasquale T (2003) Vacuum-assisted wound closure (VAC therapy) for the management of patients with high-energy soft tissue injuries. J Orthop Trauma 17: 683–688
15. Cross WW 3rd, Swiontkowski MF (2008) Treatment principles in the management of open fractures. Indian J Orthop 42:377–386
16. Court-Brown CM, Rimmer S, Prakash U, McQueen MM (1998) The epidemiology of open long bone fractures. Injury 29:529–534

12 Soft Tissue Coverage in Complex Fractures of the Limbs

Carmen Iglesias-Urraca

12.1 Introduction

Evolution in reconstructive surgery, especially the microsurgery techniques, has substantially influence limb salvage surgery. Mangled extremity is, nowadays, a challenge to reconstructive surgeons. These injuries have a significant clinical complications like wound infection, soft tissue lost, compartment syndrome, non-union, pain and stiffness, joint contracture, chronic osteomyelitis, reflex sympathetic dystrophy and even amputation. Severe open fracture must be considered a surgical emergency and needs a sophisticated management protocol and a specialised team.

Mangled extremities are severe injuries of at least three of five of the following extremity system: skin and integument, nerve, bone, vascular or muscle [1].

Characteristics of injury are noted in Table 12.1. There are many classifications of extremity injuries. Most include, to a varying degree, the destruction of bone, tendon, nerve, soft tissue and vascular structures. The modified Gustilo-Anderson classification of open fractures is shown in Table 12.2 [2, 3]. This scheme was initially derived to stratify the risk of infection in open fractures. The classification, although fairly simple, provides a guideline for treatment. The AO/ASIF classification is more extensive and considers skin, muscle, arterial and nerve damage. This is a more exhaustive classification, better to know exactly what happened, but more difficult to use in clinical practice.

Reimplantation must be considered in major upper limb amputation if the general conditions of the patient allow it [4]. And in the lower extremity, it must be considered if the plantar surface is intact and the reconstruction of the bone and soft tissue is possible.

12.2 Initial Preoperative Assessment

Initial stabilisation and diagnosis should be performed via a multidisciplinary approach according to the established advance trauma life support (ATLS) protocol. For emergency extremity trauma, immediate attention primarily targets haemorrhage

Table 12.1 Characteristics of a severely injured extremity

High-energy wounding mechanism
Severe vascular injury
Soft tissue damage
Complex fractures
Bone loss
Joint dislocation
Nerve injury
Gross contamination

Three or more of them defined the extremity as a mangled extremity

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Table 12.2 Gustilo-Anderson classification of open fractures [2]

I	Laceration <1 cm, low-energy trauma, minimal contamination
II	Laceration >1 cm, severe soft tissue damage
III	Extensive soft tissue loss
IIIa	Adequate coverage of fracture
	High-energy fracture regardless of the size of the wound
IIIb	More extensive injury, gross contamination of the soft tissue, periosteal stripping, soft tissue gaps with bone exposure
IIIc	Arterial injury requiring repair

Table 12.3 Prognostic factors for limb salvage following complex extremity trauma

Time
Direct correlation between delay in revascularisation and limb loss
Mechanism
Blunt and high-energy velocity penetration have worse prognosis than low velocity
Anatomy
Lower leg vessels have worse prognosis than upper extremity vessels. Popliteal the worst
Associated injuries
Age and physiological conditions
Clinical presentation
Shock and obvious limb ischaemia pose worse outcome
Environmental circumstance

control. Once the patient is stabilised, the clinical evaluation is performed. Assessment of the injured extremity must consider trauma mechanism, wound dimensions and all functional components (soft tissues, nerves, vessels, bones). Radiographic imaging and Doppler sonograhy or angio-TC are essential in case of vascular injury.

In reality, the mangled extremity is an injured extremity where amputation is a possible outcome. The decision between amputation and salvage is being made in the emergency department and operating room [5]. The mechanism, circumstances and time of injury, comorbidities, medications, age and preinjury functional status are all important parts of the medical history. Physical findings as pulse, perfusion, degree of soft tissue and bony injury must be quickly discerned (Table 12.3).

Studies show that delay of the first operative procedure is associated with a significantly increased probability of amputation in patients with an open tibial fracture. Nowadays, we know that the prognosis of these fractures depends on the soft tissue damage. So plastic surgeons must be involved in care immediately after admission instead of rather days to perform the appropriate plan of treatment avoiding desiccation necrosis and various steps in debridement.

12.3 Indications for Limb Salvage Procedure vs. Amputation

The decision to proceed with primary amputation is one of the most difficult decisions. The practical questions are as follows: Is the limb feasible for salvage? Is the limb salvage advisable? (Will limb salvage hasten the patient's demise? If choosing salvage, what is the order of the steps?) When does salvage fail and secondary amputation is required?

This decision must be considered individually for each patient, considering not only local trauma site but also the age, presence of other concomitant injuries, patient comorbidities, socioeconomic status and patient motivation.

Numerous algorithms have been established to estimate the viability of damaged tissue and to assist in determining whether amputation is necessary [6]. These included the Mangled Extremity Severity Score (MESS), the Limb Salvage Index (LIS), the Predictive Salvage Index (PSI) and the Hannover Fracture Scale (HFS). These scores consider the vascular injury as a major prognostic factor and also include the local tissue status and the shock time. All of them must be used after the debridement. Comparison between them is in Table 12.4. These tools, unfortunately, were still debated over definitive criteria for amputation, and this led to the recent multicentre study entitled the Lower Extremity Assessment Project (LEAP), carried out at eight level I trauma centres in the USA. This study looked prospectively at patients with traumatic amputations of the lower leg, Gustilo III (A–C) injuries, lower leg devascularising injuries, major soft tissue injuries of the lower leg, open pilon fractures (grade III) and ankle fractures (grade IIIB) and severe open hindfoot and midfoot

Table 12.4 Comparison between different scores

	PSI	MESS	LSI	HFS-97	NISSA
Age		+			+
Shock		+			+
Ischaemia	+	+	+	+	+
Skeletal trauma	+		+	+	
Muscle trauma	+		+		
Skin trauma			+	+	
Nerve trauma			+	+	+
Vessel trauma			+		
Soft tissue trauma		+			+
Contamination				+	+
Time of treatment	+				

PSI Predictive Salvage Index, *MESS* Mangled Extremity Severe Score, *LSI* Limb Salvage score, *HFS-97* Hannover Fracture Scale, *NISSA* Nerve, Ischemia, Soft tissue, Skeletal, Shock, Age

injuries with degloving and nerve injury. The goal of the study was to define the characteristics of the individuals sustaining lower extremity trauma. A total of 601 patients were enrolled, and the patient demographic was primarily male (77 %), Caucasian (72 %) and young (71 % between 20 and 45 years old). The results demonstrated that the patients who sustained a high degree of extremity trauma had several disadvantages prior to their injury (social, economic, personality), and that quality of life and functional outcome data seemed more related to these than to the injury [7].

The principle life before the limb will obviously be the primary objective. In this case, reimplantation remains fairly uncommon. Indications for primary amputation may include very advance patient age, prolonged warm ischaemia time and presence of life-threatening concomitant injuries. In case of trauma amputation, warm ischaemia can be tolerated up to 8 h and cooling may extend the safe time to reimplant to 24 h. Risk factors that may contribute to or predict the need for amputation are in Table 12.5.

The plantar sensation is no longer a limiting prognostic factor. Bose et al. showed comparable sensation outcomes in plantar sensation between patients initially lacking and patients with permanently preserved plantar sensibility at 2 years [8].

Table 12.5 Risk factors that may contribute to or predict the need for amputation

Gustilo III-C tibial injuries
Sciatic or tibial nerve injury
Ischaemia >4–6 h/muscle necrosis
Crush or destructive soft tissue injury
Significant wound contamination
Multiple/severely comminuted fractures; segmental bone loss
Old age or severe comorbidity
Apparent futility of revascularisation or failed revascularisation

From an economic point of view, unless amputation is inevitable, surgeons must always consider limb salvage, which will yield lower costs and higher utility compared with amputation [9].

Thus, a surgeon must perform realistic risk-benefit stratification to determine whether amputation is justified. Individual patient assessment remains the key step in determining if limb salvage procedure is indicated. The limb salvage is indicated if this extremity will be, in future, functional and without pain or chronic infection. Surgeons should try to optimally meet outcome expectations while keeping morbidity at the lowest possible level.

12.4 Timing

Godina was the first surgeon who introduced the concept of emergency coverage in the 1980s [10]. To reduce the incidence of non-union fracture and osteomyelitis is necessary: (1) early and adequate debridement of traumatic zone of injury (2) followed by immediate restoration of affected longitudinal structures and (3) early defect coverage by transferring a well-vascularised tissue. The importance of early soft tissue coverage after removing all devitalised tissues has been demonstrated, thereby preventing bacterial colonisation. Complex and contaminated wounds should be converted into surgically clean wounds to allow an appropriate closure [11, 12]. All of these extremities result from high-energy trauma, and this means that they develop a zone of soft tissue injury much larger than the wound and bony fracture site itself. The traumatic zone of injury includes areas of increasing soft tissue destruction as the point of impact is approach [13]. The direct trauma contact area is a zone of necrosis, with adjacent tissue becoming a zone of stasis and the surrounding region developing into a zone of hyperaemia. These areas, with stasis and hyperaemia, that are marginally viable at the time of initial injury eventually die or become replaced by a fibrotic scar. Both the soft tissue and the bone tissue are traumatised and if not adequately treated during the initial management will develop soft tissue defects, non-union and osteomyelitis. Also, in the microvascular reconstruction, the vessels in the zone of injury are fibrotic, without suitable veins and difficult to dissect. The average distance between the anastomotic area and the zone of injury was around 45.7 mm in mangled limbs. Initial appreciation of the zone of injury and the extent of recipient vessel damage are crucial for developing a strategy for fracture stabilisation, debridement and soft tissue coverage, which together determine the success of the patients' limb salvage outcome.

Debridement of damaged tissues is the most important procedure in treating mangled lower and upper limbs. Any soft tissue with bleeding and destruction activates the humoral and cellular mechanisms to stop bleeding and to resist the infection. The body's response to injury is a sequence of overlapping reactions that can be divided into four phases: (1) The initial coagulation phase, which takes some minutes, is followed by (2) an inflammatory phase lasting several hours, and then (3) the granulation phase takes place for days, which is finally followed by (4) the scar formation phase, a remodelling process that lasts for weeks.

In the inflammatory phase, the injured tissue suffers an oxygen deficiency because of the initial underperfusion that leads to anaerobic metabolism of the cells. Therefore, adequate surgical debridement of devitalised tissue in the injured areas reduces the risk of hypoxia and infection. The timing of surgery also plays a role in the clinical outcome. Therefore, the timing for making the debridement is paramount. As we know that the inflammatory response occurs in hours, debridement should be done within 6 h of an open fracture.

12.5 Surgical Technique

12.5.1 Radical Debridement

Radical and early debridement is a key step in surgical management and one of the most powerful tools for infection control. Radical means that the surgeon should debride all of the devitalised and potentially contaminated tissue. Debridement should be done like resection of a malignant tumour, that is to say, always to the healthy tissue, removing all the necrotic, devitalised tissue and even the uncertain vital tissue. We have to transform the open fracture into a healthy and without dead spacer defect. We have to begin from outline to inner. Only we have to be careful in tendons and neurovascular structures. In case of damage or complete transection, they must be repaired with a tendon, vessel, nerve or bone graft. This is the best time to make it. Therefore, the next surgery is more difficult and the clinical outcomes are worse. Fasciotomy should be performed if there were warm ischaemia and accumulated haematoma. Figure 12.1 shows the evolution of the plastic reconstruction concept.

12.5.2 Fracture Stabilisation

In the past the initial treatment of an open fracture was the use of an external device, always. Nowadays, recent studies show no difference between an internal fixator (nail or plates) and external fixator. An internal fixator is recommended if soft tissue procedures are done expeditiously. Also, an adequate fixation of the fractures reduces the incidence of infection or non-union. A trauma surgeon should choose the best fixation to the fracture forgetting about the soft tissue [14].

We should use the so-called fix and flap concept. Gopal et al. demonstrated less mobility in terms of non-union and osteomyelitis if the

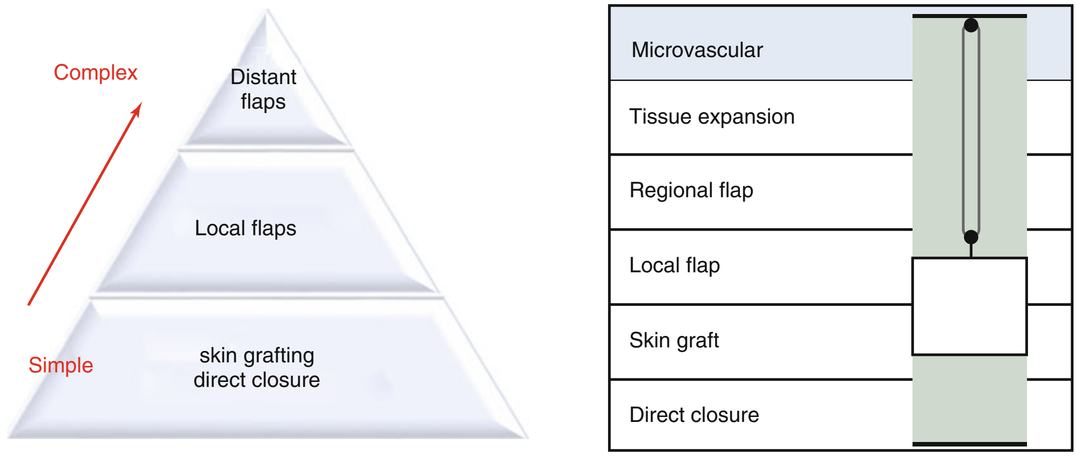

Fig. 12.1 Evolution of the plastic reconstruction concept: from the progressive reconstructive ladder to the new concept, each defect requires a specific type of reconstruction (the lift concept)

Fig. 12.2 This case example shows the importance of radical debridement in extremity reconstruction to allow tendon mobility: (**a**) preoperative view, (**b**) intraoperative view, (**c**) postoperative view

sequence of treatment is aggressive debridement, fracture stabilisation and well-vascularised coverage in only one stage [15].

12.5.3 Soft Tissue Reconstruction

Since the imposition of microsurgery in the 1960s, the traditional concept of the "reconstructive ladder" has undergone a substantial evolution [16]. In the past, the primary objective was a simple wound closure. Modern microsurgery allows reconstruction of complex bone and soft tissue defects with excellent aesthetic and functional outcomes (Fig. 12.2). Thus, reconstructive surgery becomes a reconstructive lift. Although local flaps and skin graft are still considered in reconstructive surgery, they are associated with an increased rate of wound complications and compromises concerning results. Today, local and pedicle flaps are, in most of the cases, damaged and unusable. Further compromise of a severely injured extremity by sacrificing local tissue should be avoided.

Therefore, free tissue transfer provides the most appropriate repair for severely injured extremities. In general there are four principal indications for free flap coverage of traumatised extremities: (1) soft tissue defects in the distal third of the leg, (2) soft tissue defects with functional defects in the upper and lower extremities, (3) extensive defects in the lower or upper extremities at any level and (4) salvage free flaps in non-reimplantable amputation. Local flaps must be considered in low-energy trauma patients with a small soft tissue defect (less than 5 cm) and only when the surgeon is completely sure that the local tissue is not damaged. Skin graft has only one indication: non-complicated defects, that is, defects without tendon, bone, nerve or vascular exposure.

Modern techniques range from supermicrosurgery free tissue transfer, functional composite free flaps and pre-expanding and chimeric flaps to innervated functional myocutaneous flaps.

12.5.3.1 Time of Soft Tissue Reconstruction

The soft tissue reconstruction must be done as soon as possible [17]. Flap closure timing is divided into three categories: (1) primary free flap closure (12–24 h), (2) delayed primary free flap closure (2–7 days) and (3) secondary free flap closure (>7 days).

Primary free flap closure with primary reconstruction is defined as a combination of definite functional reconstruction of longitudinal structures (bone, vessels, nerves and tendons using grafts if it is necessary) and flap coverage following surgical debridement as a single-step procedure within a period of 24 h.

Delayed primary reconstruction is defined as free flap defect closure within 2–7 days after the trauma. Again, definitive reconstruction of longitudinal structures must be performed and it is a single-step procedure too.

Secondary free flap closure signifies closure with a free flap later than one week after trauma. In general, reconstruction of soft tissue and temporary bone stabilisation may be achieved. The definitive reconstruction of longitudinal structures and bone defects must be performed later.

Primary flap cover for crucial closure prevents further tissue damage caused by desiccation and facilitates vascular ingrowing from the new surrounding soft tissue. Well-vascularised flaps provide healthy tissue, thereby allowing a radical debridement of the trauma zone. Because the primary goal in the treatment of complex extremity injury is a quick and functionally optimal recovery, the treatment of choice is the primary free flap cover within the first 24 h after injury. This minimises morbidity, tissue infection rate, requirement for secondary surgical procedures, rehabilitation time and total duration of hospital stay.

12.5.3.2 Flap Selection

Because of the huge variety of flaps available for reconstruction, flap selection must aim to optimally meet the specific functional and aesthetic requirements of the recipient site such as tissue volume and surface, vascular pedicle length and functional exigencies [18]. Flaps with different tissues (bone, muscle, tendon, nerve, adipose, fascia and skin) are referred as composite flaps. Each flap has its property characteristic of functionality, durability, vascular supply and blow flow. Nowadays, there is an upcoming trend towards using the fasciocutaneous flaps in reconstructive surgery [18]. There was no statistical difference in terms of flap survival, rate of postoperative infections, chronic osteomyelitis and stress fractures between coverage with muscle flaps and coverage with a fasciocutaneous flap. Both are useful to cover three-dimensional defects [19]. Only in muscle function reconstruction is a muscle flap required [20, 21].

Special attention must be paid to the reconstruction of the highly sensitive weight-bearing area of the foot. Here, choice of the flap remains controversial, and it is mainly determined by the localisation of the defect.

Evaluation of the foot defects includes the dimensions of the defect, localisation (weight-bearing or not areas), exposure of noble structures, age of patient and concomitant disease. Hidalgo and Shaw en 1986 [22] provided an algorithm of reconstruction as follows: type 1, defects less than 3 cm^2, local flaps in weight-bearing areas (Fig. 12.3) and skin graft in non-weight-bearing areas; type 2, defects of 3 or more than 3 cm^2 without bone involvement, a free fasciocutaneous flap or muscle flap covered with skin graft; and type 3 large defect with bone loss and a free osteocutaneous flap. The controversial items in foot reconstruction are muscle vs. fasciocutaneous flap and if it is necessary the nerve coaptation. Some have argued that thin perforator flaps would reduce shear forces and improve the stability compared to muscular and fasciocutaneous flaps [23]. It is true that these forces are reduced within the flap, but the interface between the flap and the bone would still be the potential site of shearing. In the controversial nerve coaptation, numerous studies have shown that coaptation

Fig. 12.3 Reconstruction of small defect in the weight-bearing area with a propeller perforant flap: (**a**) preoperative view, (**b**) intraoperative view, (**c**) postoperative view

improved early sensation, but by 1 year, most of the authors noted good return of sensibility in non-neurotised flaps [24, 25].

Besides adequate bone stabilisation and soft tissue coverage, restoration of impaired physiological function is one of the key objectives in extremity salvage. Microsurgical tissue transfer has opened a wide variety of possibilities to re-establish function of impaired limbs. If local repair or tendon transfer and/or nerve grafting is not practical for localised trauma, free functional muscle transplantation will be the treatment of choice. Several previous studies proved the applicability of this concept. Basic functions of skeletal muscles include posture maintenance, joint stabilisation and active movement. In functional muscle transfer, the surgical goal is to supply sufficient resting tension while at the same time providing an optimal range of motion. Therefore, muscle selection must target optimal range of motion. If necessary, functional muscle flaps can be transplanted as composite flaps including bone and soft tissue. Commonly used flaps include the gracilis, rectus femoris, latissimus dorsi and tensor fascia lata flap. In lower extremity reconstruction, the main functional goal is the restoration of active hip, knee and ankle dorsiflexion/extension. In upper extremity reconstruction, the gracilis and pectoral muscles are considered to establish the elbow and long finger reconstruction. Usually functional restoration after trauma or severe nerve injury consists of a complex combination of tendon transfer, nerve reimplantation and muscle transfer [26].

In a one-stage "functional" reconstructive approach, the reconstruction is not simply for defect coverage and bone or tendon repair, but may also include tendon transfer for nerve palsy and tendon defect and functional muscle or myocutaneous transfer for composite functioning [27]. Multiple bony metacarpal defects as well as soft tissue coverage can be adequately addressed simultaneously with a free fibular osteocutaneous flap osteotomised into two or three struts [28]. The extensor tendon disruption should be repaired, and the missing or non-functional interossei can be reconstructed using splinted palmaris longus extension graft from the ECRL to the lateral bands (Brand method) to achieve PIP and DIP joint extension. In the case of forearm avulsion with loss of the flexor muscle group and median nerve damage, a one-stage strategy may include defect reconstruction with a gracilis functioning muscle flap for finger flexion, remnant flexor muscle utilisation or uninjured extensor tendon transfer for thumb flexion and opponensplasty for thumb ray opposition [29]. To accomplish the goal of one-stage functional reconstruction, a free composite flap inclusive of different components can be custom-made to fulfil every defect in the recipient site: the fibula, ALT and forearm flaps. If the reconstruction requires multiple tendon transfers from both the flexor and the extensor groups even though the defect is on one side, such as the volar aspect, the surgeon has to prioritise the order of tendon harvest and choose from one of the two muscle groups but not both concurrently. One-stage early reconstruction is preferable to shorten the disability time and to allow for earlier rehabilitation to have better recovery and improved outcomes (Fig. 12.4). In some situations, staged reconstruction is inevitable.

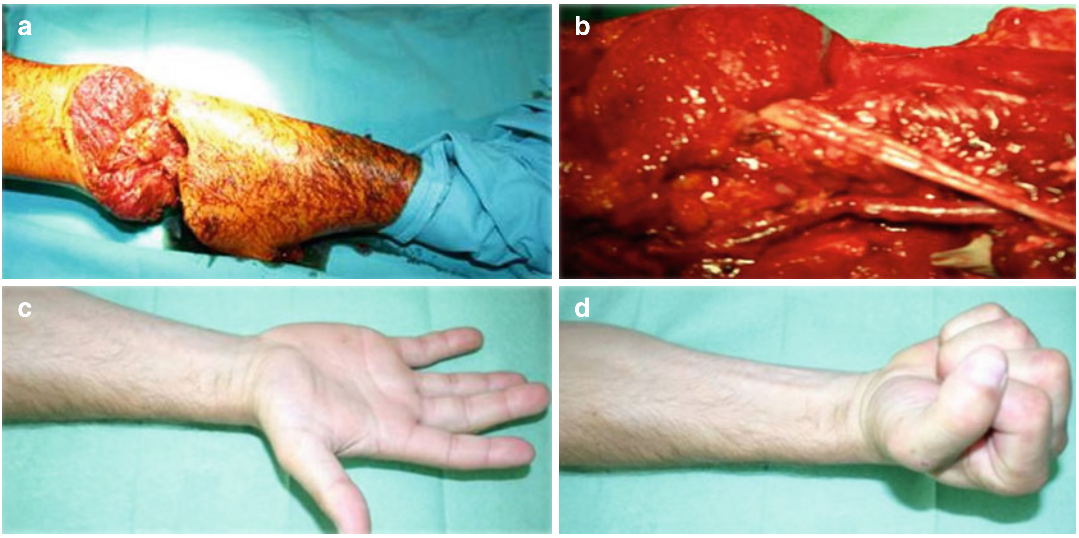

Fig. 12.4 The soft tissue reconstruction must include the vascular, nerve and tendon repair. Every component must be repaired the first time to reduce the rate of complications and allow early rehabilitation: (**a**) preoperative view, (**b**) intraoperative view, (**c**, **d**) postoperative views

However, all upper limb reconstructions should have a well-thought-out strategic road map consisting of an optimal plan A and a backup plan B, or even a plan C, to achieve an effective functional restoration.

In hand surgery, another highly sophisticated and well-established technique is the free toe-to-hand transfer. This transfer aims to restore the length, stability, aesthetic apiece and especially pinch-and-grasp function of traumatised hands. Single or multiple toe transplantations can effectively help the patient to regain acceptable function and appearance, even after traumatic multiple digit amputations.

One controversy is the use of muscle vs. fasciocutaneous flap (Fig. 12.5). Fasciocutaneous flaps may be superior to muscle in fractures around the ankle or the knee, thereby avoiding skin grafts which can be ulcerated with minor trauma. Muscle in diaphyseal fractures would aid healing and the aesthetic appearance is not bad [30, 31]. However, they can be difficult to elevate for secondary procedures such as bone grafting; an alternative that retains the biological benefits of muscle apposition is the use of chimeric flaps, such as a free anterolateral thigh flap that includes a segment of the vastus lateralis.

So, there is no standardisation of the flap used in the extremity reconstruction. A key principle is the individual flap selection depending on the recipient site requirements. Remember that the core concept in plastic surgery has been the replacement of "like-with-like" tissue [32, 33].

12.5.3.3 Vessel Selection

Both the upper and lower extremities have dual arterial supplies, for example, the radial and ulnar arteries or anterior and posterior tibial arteries. Sometimes, after confirmation of reliable distal flow, one of them must be sacrificed for use as the flap recipient vessel in microsurgical reconstruction. Recipient flow is better preserved, however, by making a T-anastomosis [34]. This is especially useful in patients with diabetes, chronic vasculopathy or traumatic loss of one dominant vessel; because distal perfusion of the lower extremity is crucial in these patients, the donor vessel can also be preserved with T-anastomosis. When the entire blood flow from a recipient artery is concentrated on the pedicle of the flap after end-to-end anastomosis, the flap is prone to congestion, especially if a large perforator flap is used or if there is a size discrepancy in the vascular anastomosis. Blood flow and pressure can be

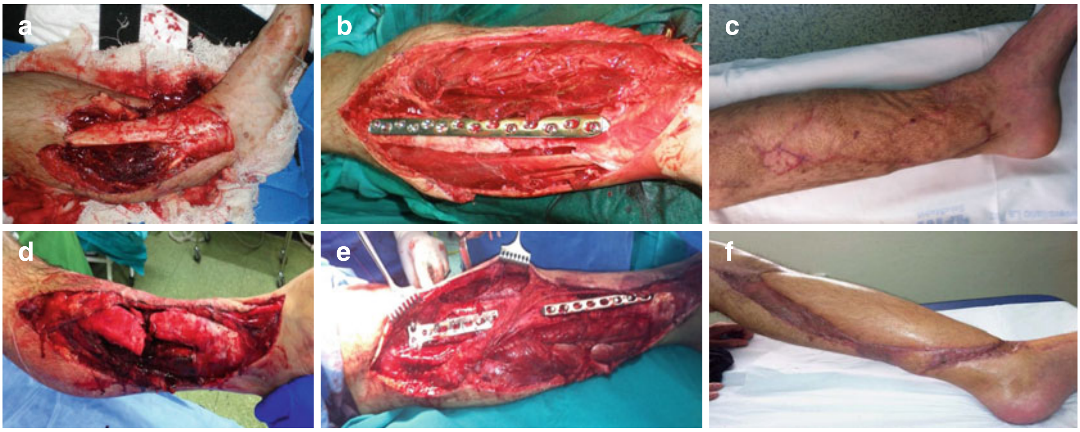

Fig. 12.5 Reconstruction with musculocutaneous flap (**a**–**c**) vs. fasciocutaneous flap (**d**–**f**). No differences exist between them regarding fracture healing and aesthetic result. However, the fasciocutaneous flap is easier to reelevate

dispersed to both the flap and the distal recipient vessel by a T-anastomosis until the flow equilibrates.

The flow-through free flaps allow arterial reconstruction and soft tissue coverage in the same stage [35]. Without a flow-through flap, damaged extremities usually require second-stage operations, with vein grafts in the first stage and skin flaps or tissue transfers in the second stage. The ideal interposition pedicle vessels for the flow-through flaps seem to be large-calibre, long trunk vessels with adequate septocutaneous perforators. The radial forearm flap and the anterolateral flap are used to these proposes. Both have a long pedicle enough to repair a long arterial gap. However, a radial forearm flap has several drawbacks, including sacrifice of the radial artery, skin graft loss with tendon exposure and displeasing appearance of the skin-grafted donor site, in addition to which, a large flap size cannot be obtained. Flow-through anterolateral thigh flap has several advantages, including large cutaneous area, acceptable donor site morbidity, adjustable thickness and the possibility of combining the adjacent muscle and fascia lata.

Therefore, the proper selection of recipient vessels appears to have the utmost importance in the success of a microvascular tissue transfer. One of the most important problems in the trauma surgery is the selection of the healthy vessel out of the zone of injury. To avoid it, the surgeon can use bypass or arteriovenous loop or choose the distal anastomosis.

- The use of interposition vein grafts has been reported to be associated with a higher incidence of flap loss than regular transfers [36]. Using vein grafts to reach healthy recipient vessels remote from the zone of injury is much safer option than the suboptimal selection of the recipient vessels to decrease operative time or to avoid a more complex procedure. Pre-planned vein graft interposition in a flap transfer does not alter the operative course substantially.
- Other authors have demonstrated the usefulness of arteriovenous loops as an alternative in which a constant high blood flow is established by shunting the arterial and venous portion, thereby achieving high-flow perfusion of the newly created loop [37]. The free flap transfer may then be performed either as a simultaneous procedure or at the second stage after perfusion has been ensured for an appropriate time interval. These are indicated if the bypass is longer than 20 cm.
- There is another possibility to avoid the damage vessels: Choose the recipient site distal to the zone of injury [38]. Distal vessels may have potential problems associated with blood flow traversing the injured tissue. Furthermore, these vessels may be smaller. On the other

hand, distal vessels are more superficial, making the anastomosis easier; require a shorter pedicle; and may obviate the possibility of tunnelling the pedicle or interposition grafts. The critical step is to evaluate the patency of the recipient vein intraoperatively by injecting heparinised saline after division and noting an unresisted flush.

- Anastomosis to retrograde flow, generally distal to the defect [39].
- Supermicrosurgery or perforator-to-perforator surgery represents a modern technique of free tissue transfer in which the diameter of the anastomosis does not exceed 0.8 mm. Donor site tissue is harvested in a superficial approach reducing the donor site morbidity. But, this dissection results in pedicles in limited length and calibre. Subsequently, in most cases, one cannot respect the basic principle of performing anastomosis outside of the trauma zone. So this is a limited indication technique.

Early and radical debridement and early flap coverage of open fractures achieve infection-free union. During the past decades, reconstructive microsurgery has strongly influenced the management of complex extremity trauma [40]. Isolated complex extremity injury requires immediate specialised attention via an interdisciplinary approach [41, 42]. Whenever possible, all efforts must be focused on primary surgical reconstruction and soft tissue coverage at the earliest point of time. Any delay in treatment may lead to a higher rate of complications, a prolonged hospital stay, an increase in invalidity and a higher cost treatment [43, 44]. The main goal of reconstructive microsurgery must be an optimal functional and aesthetic reconstruction, meeting the individual trauma site requirements with minimal donor site morbidity.

Conclusions

Complex fractures of the limbs pose a clinical challenge for the multidisciplinary team that needs to treat them. The current advances in soft tissue flap reconstruction techniques have significantly improved the results of the limb salvage attempts. Understanding the reconstructive concepts of zone of injury, aggressive debridement and timing and the possibilities of flap coverage is essential to complete limb salvage in a timely and appropriate fashion. Complex extremity injury requires immediate and specialised attention via an interdisciplinary approach. The steps in surgical management include radical tissue debridement, adequate stabilisation and reconstruction of viable structures by the use of autologous blood vessels or nerve grafts and bone and soft tissue reconstructions with a "custom-fit" flap. Generally all of them must be done in a unique surgery. These are the most powerful tools for infection control and to get the best results.

References

1. Pasquale MD, Frykberg ER, Tinkoff GH (2006) Management of complex extremity trauma. Bull Am Coll Surg 91:36–38
2. Gustilo RB, Anderson JT (1976) Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am 58: 453–458
3. Gustilo RB, Mendoza RM, Williams DN (1984) Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 24:742–746
4. Chen MW, Narayan D (2009) Economics of upper extremity replantation: national and local trends. Plast Reconstr Surg 124:2003–2011
5. Chung KC, Shauver MJ, Saddawi-Konefka D, Haase SC (2011) A decision analysis of amputation versus reconstruction for severe open tibial fracture from the physician and patient perspectives. Ann Plast Surg 66:185–191
6. Ly TV, Travison TG, Castillo RC et al (2008) Ability of lower-extremity injury severity scores to predict functional outcome after limb salvage. J Bone Joint Surg Am 90:1738–1743
7. MacKenzie EJ, Bosse MJ, Kellam JF et al (2002) Factors influencing the decision to amputate or reconstruct after high-energy lower extremity trauma. J Trauma 52:641–649
8. Bosse MJ, MacKenzie EJ, Kellam JF et al (2002) An analysis of outcomes of reconstruction or amputation after leg-threatening injuries. N Engl J Med 347: 1924–1931
9. MacKenzie EJ, Bosse MJ, Castillo RC et al (2004) Functional outcomes following trauma-related lower-extremity amputation. J Bone Joint Surg Am 86: 1636–1645
10. Godina M (1986) Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg 78:285–292
11. Davis E, Matthew D, Chung K (2012) Relationship between timing of emergency procedures and limb

amputation in patients with open tibia fracture in the United States, 2003 to 2009. Plast Reconstr Surg 130(2):369–378
12. Enninghorst N, McDougall D, Hunt JJ, Balogh ZJ (2011) Open tibia fractures: timely debridement leaves injury severity as the only determinant of poor outcome. J Trauma 70:352–356
13. Isenberg JS, Sherman R (1996) Zone of injury: a valid concept in microvascular reconstruction of the traumatized lower limb? Ann Plast Surg 36:270–272
14. Worlock P, Slack R, Harvey L (1994) The prevention of infection in open fractures: an experimental study of the effect of fracture stability. Injury 25:31–38
15. Gopal S, Majumder S, Batchelor AG et al (2000) Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. J Bone Joint Surg Br 82:959–966
16. Mathes SJ, Nahai F (1997) The reconstructive triangle, a paradigm for surgical decision making. In: Mathes SJ, Nahai F (eds) Reconstructive surgery: principles, anatomy and technique, vol 1, 1st edn. Churchill Livingstone and Quality Medical Publishing Inc, New York, pp 9–36
17. Rajasekaran S (2007) Early versus delay closure of open fractures. Injury 38:890–895
18. Parrett BM, Matros E, Pribaz JJ, Orgill DP (2006) Lower extremity trauma: trends in the management of soft-tissue reconstruction of open tibia-fibula fractures. Plast Reconstr Surg 117:1315–1322
19. Chan J, Harry L, Williams G et al (2012) Soft-tissue reconstruction of open fractures of the lower limb: muscle versus fasciocutaneous flaps. Plast Reconstr Surg 130(2):284e–295e
20. Harry LE, Sandison A, Pearse MF et al (2009) Comparison of the vascularity of fasciocutaneous tissue and muscle for coverage of open tibial fractures. Plast Reconstr Surg 124:1211–1219
21. Yazar S, Lin CH, Lin YT et al (2006) Outcome comparison between free muscle and free fasciocutaneous flaps for reconstruction of distal third and ankle traumatic open tibial fractures. Plast Reconstr Surg 117: 2468–2475
22. Hidalgo DA, Shaw WW (1986) Reconstruction of foot injuries. Clin Plast Surg 13:663–680
23. May JW Jr, Rohrich RJ (1986) Foot reconstruction using free microvascular muscle flaps with skin grafts. Clin Plast Surg 13:681–689
24. Scott T, Hollenbeck ST, Shoshana W, Issei K et al (2010) Longitudinal outcomes and application of the subunit principle to 165 foot and ankle free tissue transfers. Plast Reconstr Surg 125(3):924–934
25. Sönmez A, Bayramicli M, Sönmez B (2003) Reconstruction of the weight-bearing surface of the foot with nonneurosensory free flaps. Plast Reconstr Surg 111:2230–2236
26. Lin C-H, Nguyen A (2010) Avoiding unfavorable results in microsurgical reconstruction in upper-extremity trauma. Semin Plast Surg 24(1):67–76
27. Hsu CC, Lin YT, Lin CH (2009) Immediate emergency free anterolateral thigh flap transfer for the mutilated upper extremity. Plast Reconstr Surg 123: 1739–1747
28. Lin CH, Wei FC, Rodriguez ED, Lin YT et al (2005) Functional reconstruction of traumatic composite metacarpal defects with fibular osteoseptocutaneous free flap. Plast Reconstr Surg 116:605–612
29. Lin CH, Wei FC (2000) Immediate Camitz opponensplasty in acute thenar muscle injury. Ann Plast Surg 44:270–276
30. Liu R, Schindeler A (2010) The potential role of muscle in bone repair. J Musculoskelet Neuronal Interact 10:71–76
31. Demirtas Y, Kelahmetoglu O, Cifci M et al (2010) Comparison of free anterolateral thigh flaps and free muscle-musculocutaneous flap in soft tissue reconstruction of lower extremity. Microsurgery 30:24Y31
32. Heller L, Levin LS (2001) Lower extremity microsurgical reconstruction. Plast Reconstr Surg 108: 1029–1041
33. Yaremchuk MJ, Brumback RJ, Manson PN (1987) Acute and definitive management of traumatic osteocutaneous defects of the lower extremity. Plast Reconstr Surg 80:1–14
34. Kim JT, Kim CY, Kim YH (2008) T-Anastomosis in microsurgical free flap reconstruction: an overview of clinical applications. J Plast Reconstr Aesthet Surg 61:1157–1163
35. Sananpanich K, Yuan Kun T, Kraisarin J et al (2008) Flow-through anterolateral thigh flap for simultaneous soft tissue and long vascular gap reconstruction in extremity injuries: anatomical study and case report. Injury 39S4:S47–S54
36. Khouri RK (1992) Reliability of primary vein grafts in lower extremity free tissue transfers avoiding free flap failure. Clin Plast Surg 19:773–781
37. Vogt PM, Steinau HS, Spies M (2007) Outcome of simultaneous and staged microvascular free tissue transfer connected to arteriovenous loops in areas lacking recipient vessels. Plast Reconstr Surg 120:1568–1575
38. Park S, Han SH, Lee TJ (1999) Algorithm for recipient vessel selection in free tissue transfer to the lower extremity. Plast Reconstr Surg 103:1937–1948
39. Miyamoto S, Takushima A, Okazakiet M et al (2008) Relationship between microvascular arterial anastomotic type and area of free flap survival: comparison of end-to-end, end-to-side, and retrograde arterial anastomosis. Plast Reconstr Surg 121:1901–1908
40. Tu Y-K, Yen C-Y (2008) Soft tissue injury management and flap reconstruction for mangled lower extremities. Injury 39S4:S75–S95
41. Arnez Z (1991) Immediate reconstruction of the lower extremity: an update. Clin Plast Surg 18:449–457
42. Naique SB, Pearse M, Nanchahal J (2006) Management of severe open tibial fractures: the need for combined orthopaedic and plastic surgical treatment in specialist centres. J Bone Joint Surg Br 88:351–357
43. Spyropoulou A, Jeng S-F (2010) Microsurgical coverage reconstruction in upper and lower extremities. Sem Plastic Surg 24:34–42
44. Durrant CA, Mackey SP (2011) Orthoplastic classification systems: the good, the bad, and the ungainly. Ann Plast Surg 66:9–12

13 Nonunion of Complex Fractures of the Limb

Aitor Ibarzábal-Gil and Elena Gálvez-Sirvent

13.1 Introduction

Inadequate response to the fracture injury sometimes occurs, resulting in delayed union or nonunion. We consider that a fracture has developed a nonunion when it lacks potential to heal without further intervention [1, 2]. In the clinical practice, we should take into account some principles: 9 months' elapsed time with no healing progress for 3 months can be considered a nonunion, we should not consider a nonunion a fracture of the shaft of a long bone less than 6 months post injury, and a central fracture of the femoral neck can sometimes be defined as a nonunion after only 3 months due to the evidence of lack of response after that period in such location.

To the clinical findings in nonunion as persistence of abnormal mobility at the fracture site, pain (absence if true nonunion is developed), and deformity, we can add some typical radiologic findings:

- Absence of bone crossing the fracture site (bridging trabeculae)
- Sclerotic fracture edges
- Persistent fracture lines (true union shows four healed cortices on the AP and lateral views)
- Lack of evidence of progressive change toward union on serial x-ray
- Failing or broken implants
- Progressive deformity
- Lack of callus (except when plating for absolute stability where it is not expected)

13.2 Etiology and Classification

Mechanical instability and disturbed vascularity are the most important factors leading to nonunion, but other factors, such as noncompliance and neuropathy, may also inhibit healing. When a nonunion is observed, an occult *infection must be taken into account*: up to 30 % of nonunion patients will have unexpected positive OR cultures.

Other risk factors for nonunion are NSAIDs, smoking, infection, vitamin D deficiency, thyroid imbalance, and occult hyperparathyroidism.

To classify nonunions, we have traditionally used a schematic based on the amount of callus or bone healing at the fracture site. The Weber-Cech classification is widely applied [2]. Hypertrophic nonunions show prolific callus formation. The environment is vascular. Because excellent healing potential is present, inadequate immobilization or stabilization usually creates the nonunion. Oligotrophic nonunions show some callus formation. The environment has a moderate healing potential. A defect in healing can be considered either primarily biological (multifactorial), biomechanical (frequently implant related or

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alignment related), or mechanical (almost always implant related). Atrophic nonunions are characterized by an absence of callus formation. The bone ends may be sclerotic or osteopenic. The healing environment is avascular. The fracture will not heal without changes to promote vascularity, such as living cells (autograft and/or free or rotational tissue transfer), removal of infection, and/or resection of nonviable bone.

Though often multifactorial, we must identify the main causes of nonunion in each case and aim our treatment to provide adequate environment for bone healing.

13.3 Diagnosis

Definition of nonunion has been given at the beginning of this chapter, but in the clinical practice it is not easy to differentiate whether a case still has potential to heal without further intervention or not.

We must take into account history, local factors, systemic factors, and radiologic images to make the diagnosis. The goals of the evaluation are to discover the etiology of the nonunion and form a plan for healing the nonunion.

Evaluation begins with a thorough history, including the date and mechanism of injury of the initial fracture. Preinjury medical problems, disabilities, or associated injuries should be noted. The specific details of each prior surgical procedure to treat the fracture and fracture nonunion must be obtained. The history should also include details regarding prior wound infections. Culture reports should be sought in the medical records.

The patient should be questioned regarding other possible contributing factors for nonunion. A history of NSAID use should be obtained and its use discontinued. Active smokers should be offered a program to halt the addiction. From a practical standpoint, however, it is unrealistic to delay treatment of a symptomatic nonunion until the patient stops smoking.

The general health and nutritional status of the patient should be assessed, since malnutrition and cachexia diminish fracture repair. The skin and soft tissues in the fracture zone should be inspected. The presence of active drainage, sinus formation, and deformity should be noted.

Active and passive motion of the joints adjacent to the nonunion, both proximal and distal, should be performed. An interesting situation worth noting is the stiff nonunion with an angular deformity. These patients may already have developed a compensatory fixed deformity at an adjacent joint. If the patient cannot place the joint into the position that parallels the deformity at the nonunion site, the joint deformity is fixed and requires correction. If the patient can achieve the position, the joint deformity will resolve with realignment of the long bone deformity.

Radiologic assessment will include plain radiographs where we will evaluate the following radiographic characteristics of a nonunion: anatomic location, healing effort, bone quality, surface characteristics, status of previously implanted hardware, and deformities. Bilateral AP and lateral alignment radiographs for lower extremity nonunions for assessing length discrepancies and deformities are mandatory. Sometimes two oblique views of the nonunion site will provide information about partial healing of the fracture. Weber and Cech classify nonunions based on radiographic healing effort and bone quality as *viable* nonunions, which are capable of biological activity, and *nonviable* nonunions, which are incapable of biological activity. Viable nonunions include hypertrophic nonunions and oligotrophic nonunions. Hypertrophic nonunions possess adequate vascularity and display callus formation. They arise as a result of inadequate mechanical stability with persistent motion at the fracture surfaces. The fracture site is progressively resorbed with accumulation of unmineralized fibrocartilage and displays a progressively widening radiolucent line with sclerotic edges. Hypertrophic nonunions may be classified as elephant foot type, with abundant callus formation, or horse hoof type, which are still hypertrophic but with less abundant callus formation. Oligotrophic nonunions have an adequate blood supply but little or no callus formation. They arise from inadequate reduction with displacement at the fracture site. Nonviable nonunions do not display callus formation and are incapable of biological activity. Their inadequate vascularity precludes the formation of periosteal and endosteal callus, and radiographically, the fracture surfaces appear partially absorbed and osteopenic.

CT scans can be used to estimate the percentage of the cross-sectional area that shows bridging bone. Nonunions typically show bone bridging of less than 5 % of the cross-sectional area at the fracture surfaces. Healed or healing fracture nonunions typically show bone bridging of greater than 25 % of the cross-sectional area. Serial CT scans may be followed to evaluate the progression of fracture consolidation. CT scans are also useful for assessing intra-articular nonunions for articular step-off and joint incongruence.

Angio CT scan will provide adequate information about vascular supply and anatomy in order to evaluate free vascularized bone grafts or flaps to cover the area when necessary.

Nuclear imaging studies are useful for assessing bone vascularity at the nonunion site and infection. Technetium-99m bone scan will show increased uptake in viable nonunions. Gallium scans are useful in the evaluation of chronic bone infections. Gallium-67 citrate localizes to sites of chronic inflammation. The combination of gallium-67 citrate and technetium-99m scans can clarify the diagnosis of a chronically infected nonunion.

MRI is occasionally used to evaluate the soft tissues at the nonunion site or the cartilaginous and ligamentous structures of the adjacent joints but is not routinely performed.

13.4 Treatment

The goals in the treatment of a nonunion are to eliminate pain, obtain osseous consolidation in correct alignment and rotation, and thus restore function of the injured limb [3–32]. Though every goal is important, some level of priority can be remarked as follows:

- Heal the bone.
- Eradicate infection.
- Correct deformities.
- Maximize joint motion and muscle strength.

In most cases consolidation can be achieved after a single, well-planned operation. When several interventions are needed, the treatment must therefore be planned so that each step anticipates the possibility of failure and allows for further treatment options. The patient needs to understand the uncertainties of nonunion healing, time course of treatment, and number of surgeries required.

The primary consideration for designing the treatment strategy is nonunion type.

Hypertrophic nonunions lack mechanical stability. Hypertrophic nonunions require no bone grafting. The nonunion site tissue should not be resected. If the method of rigid stabilization involves exposing the nonunion site (e.g., compression plate stabilization), decortication of the nonunion site may accelerate the consolidation of the bone. If the method of rigid stabilization does not involve exposure of the nonunion site (e.g., intramedullary nail fixation or external fixation), surgical dissection to prepare the nonunion site is unnecessary. In long-term established nonunion, exposure of the focus, tissue debridement, and refreshing of the bony surfaces will be necessary.

In oligotrophic nonunions an adequate blood supply is present, but there is little or no callus formation, typically as a result of inadequate reduction with little or no contact at the bony surfaces. There are recent reports of adding a small plate to a previously nailed fracture (that has evolved into delayed nonunion) with promising good results.

Treatment methods for oligotrophic nonunions include reduction of the fragments to improve bone contact, bone grafting to stimulate the local biology, and usually a combination of the two. Reduction of the bony fragments to improve bony contact can be performed with either internal or external fixation. Reduction is appropriate for oligotrophic nonunions with large surface areas without comminution where compression can be applied. Bone grafting is appropriate for oligotrophic nonunions that have poor surface characteristics and no callus formation. In the clinical practice, most cases are solved applying the same treatment we should have used at the fracture onset, improving reduction (open if necessary).

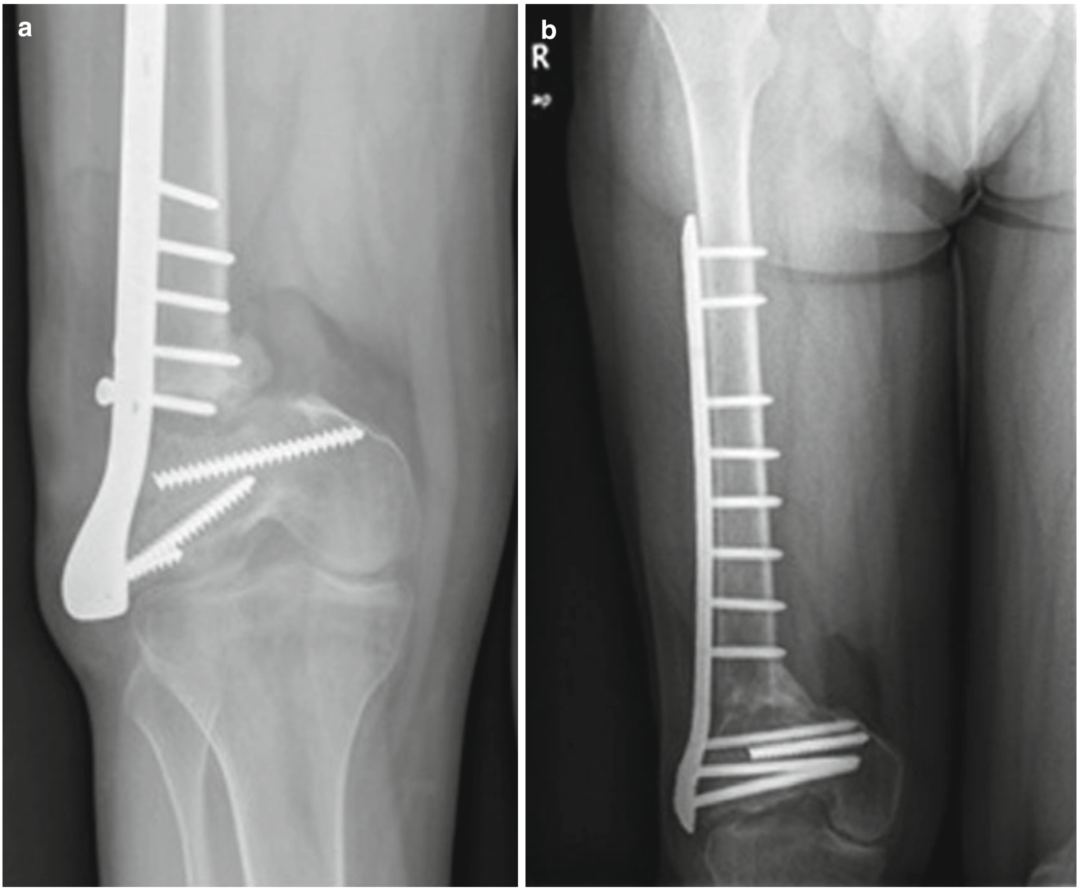

Fig. 13.1 Distal femoral nonunion (**a**). Union after 3 months of compression plating and iliac autograft (**b**)

In the upper limb with diaphyseal nonunions, we will use plate for the ulna and radius and plate or reamed nails in the humerus. Reamed nails are the gold standard in the diaphysis of the femur and tibia. When reamed nails are not possible, compression plate and autogenic bone graft are the alternatives (Figs. 13.1 and 13.2).

Atrophic nonunions are nonviable. Their blood supply is poor, and they are incapable of purposeful biological activity. Stabilization and biological improvement of the focus is mandatory. Biological stimulation is most commonly provided by autogenous cancellous graft laid onto a widely decorticated area at the nonunion site, and mechanical stability can be achieved using either internal or external fixation. Final decision largely depends on the specific pattern of the nonunion, previous treatment, anatomic location, and medical condition of the patient. In general practice the treatment consists in refreshing of the surfaces, decortication, rigid plate fixation, and autograft in the upper extremity and most metaphyseal locations [3].

In diaphyseal nonunions of the femur and tibia, without extensive bone loss, treatment is reamed nailing with a dynamic locked pattern when possible.

13.4.1 Segmental Bone Defects

Segmental bone defects associated with nonunions may be a result of high-energy open fractures with bone lost at the site of the accident

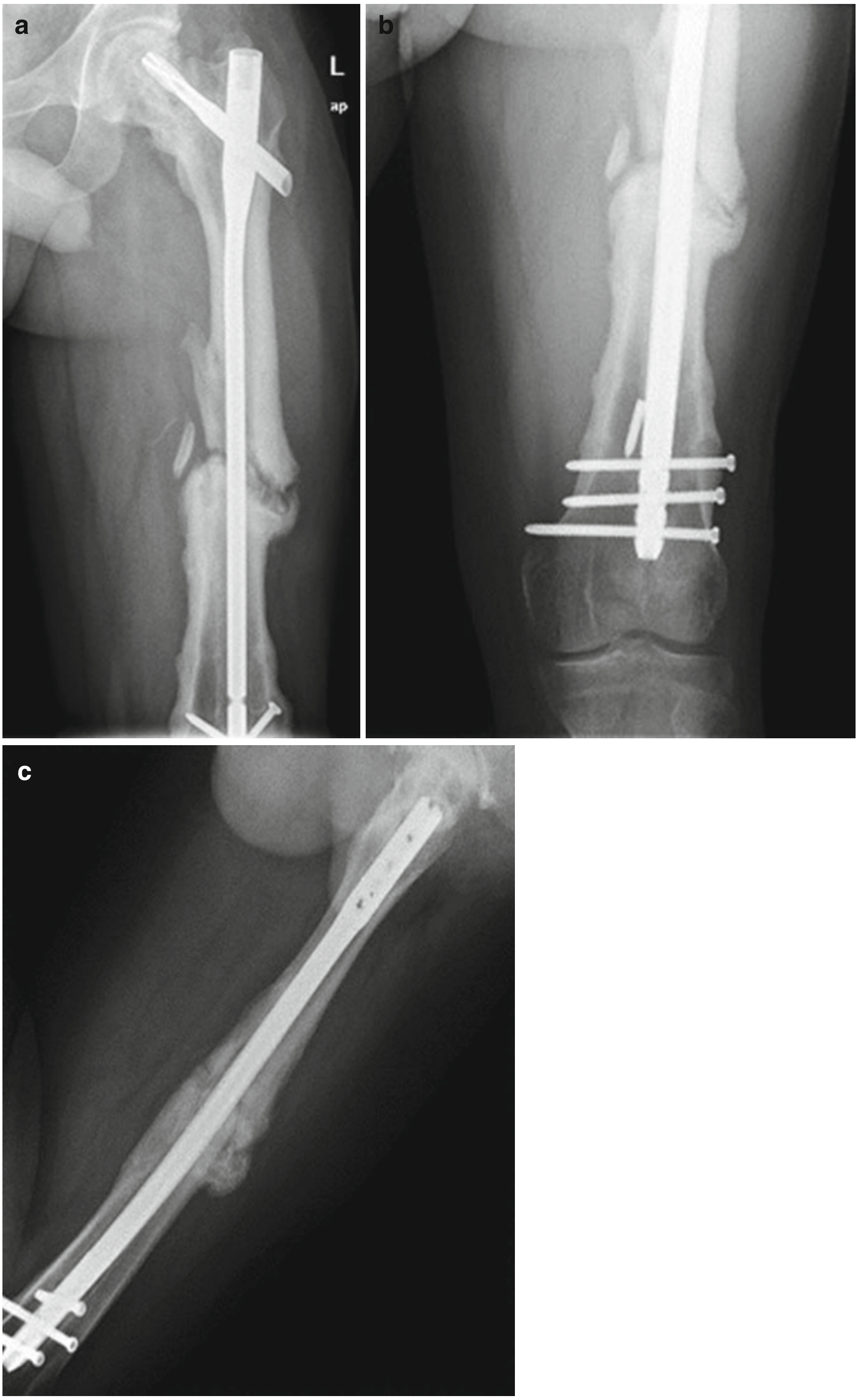

Fig. 13.2 Diaphyseal femoral nonunion after non-reamed nailing (**a**). Union achieved 4 months after reaming and exchange nailing (**b**, **c**)

or necrotic or infected bone that must be debrided in order to get fracture healing [33]. Segmental bone defects may have partial bone loss or circumferential bone loss. Though not the purpose of this chapter, general bone loss management must be mentioned. Techniques for the treatment of bone loss can be divided in these three groups: grafting, acute shortening, and distraction techniques.

In small defects iliac crest grafting with fixation is the gold standard; it is possible to perform the grafting directly or in greater than 2 cm defects with several scaffolds. Vascularized grafts are preferred in defects greater than 2 cm though it is often used as a rescue technique for failed previous treatments due to the morbidity of the giving zone. When not available, direct grafting with bone allograft, demineralized bone matrix, and calcium phosphate ceramics (hydroxyapatite, tricalcium phosphate) can be performed.

Acute shortening is the technique of choice in complete circumferential defects that cannot be grafted. Though shortening up to 2 cm in the lower limb and 3–4 cm in the humerus is well tolerated, this technique must be used with caution for complications in wound healing, and loss of strength is often observed. We use this method in distal metaphyseal femoral fractures in the older and often non-ambulating patients in order to achieve good bone contact.

Distraction techniques popularized by Ilizarov are the option in the bigger defects at the lower limb. They can be performed in several ways being bone transportation and limb lengthening, the ones used more often.

Conclusions

Because of the various nonunion types and the constellation of possible problems related to soft tissues, prior treatments, patient's health, and other factors, no simple treatment algorithms are possible. Several goals are mandatory: achieve good coverage with well-vascularized environment, adequate bone contact, and stable fixation with dynamization or compression when possible and rule out infection. We must take into account the possibility of failure and future interventions and base the treatment plan on the nonunion type and the treatment modifiers. Patient collaboration is a critical concern, and detailed explanation about the rate of success and different options including amputation must be performed prior to surgery.

References

1. Rodriguez-Merchan EC, Forriol F (2004) Nonunion: general principles and experimental data. Clin Orthop Relat Res 419:4–12
2. Brinker MR (2001) Principles of fractures. In: Brinker MR (ed) Review of orthopaedic trauma. WB, Saunders, Philadelphia
3. Rodriguez-Merchan EC, Gomez-Castresana F (2004) Internal fixation of nonunions. Clin Orthop Relat Res 419:13–20
4. Abdel-Aa AM, Farouk OA, Elsayed A et al (2004) The use of a locked plate in the treatment of ununited femoral shaft fractures. J Trauma 57:832–836
5. Abhaykumar S, Elliott DS (1998) Closed interlocking nailing for fibular nonunion. Injury 29:793–797
6. Adams CI, Keating JF, Court-Brown CM (2001) Cigarette smoking and open tibial fractures. Injury 32:61–65
7. Agiza AR (1981) Treatment of tibial osteomyelitic defects and infected pseudarthroses by the Huntington fibular transference operation. J Bone Joint Surg Am 63:814–849
8. Ahlmann E, Patzakis M, Roidis N et al (2002) Comparison of anterior and posterior iliac crest bone grafts in terms of harvest-site morbidity and functional outcomes. J Bone Joint Surg Am 84: 716–720
9. Brighton CT, Esterhai JL Jr, Katz M et al (1987) Synovial pseudoarthrosis: a clinical, roentgenographic-scintigraphic, and pathologic study. J Trauma 27:463–470
10. Brinker MR, Bailey DE (1997) Fracture healing in tibia fractures with an associated vascular injury. J Trauma 42:11–19
11. Chalidis BE, Petsatodis GE, Sachinis NC et al (2009) Reamed interlocking intramedullary nailing for the treatment of tibial diaphyseal fractures and aseptic nonunions. Can we expect an optimum result? Strategies Trauma Limb Reconstr 4:89–94
12. Ciombor DM, Aaron RK (2005) The role of electrical stimulation in bone repair. Foot Ankle Clin 10:579–593
13. Clarke P, Mollan RA (1994) The criteria for amputation in severe lower limb injury. Injury 25:139–143
14. Cobb TK, Gabrielsen TA, Campbell DC II et al (1994) Cigarette smoking and nonunion after ankle arthrodesis. Foot Ankle Int 15:64–67

15. Feldman DS, Shin SS, Madan S et al (2003) Correction of tibial malunion and nonunion with six-axis analysis deformity correction using the Taylor Spatial Frame. J Orthop Trauma 17:549–554
16. Green SA (1994) Skeletal defects: a comparison of bone grafting and bone transport for segmental skeletal defects. Clin Orthop Relat Res 301:111–117
17. Guarniero R, de Barros Filho TE, Tannuri U et al (1992) Study of fracture healing in protein malnutrition. Rev Paul Med 110:63–68
18. Guerkov HH, Lohmann CH, Liu Y et al (2001) Pulsed electromagnetic fields increase growth factor release by nonunion cells. Clin Orthop Relat Res 384:265–279
19. Gustilo RB, Nelson GE, Hamel A et al (1964) The effect of intramedullary nailing on the blood supply of the diaphysis of long bones in mature dogs. J Bone Joint Surg Am 46:1362–1363
20. Kempf I, Grosse A, Rigaut P (1986) The treatment of noninfected pseudarthrosis of the femur and tibia with locked intramedullary nailing. Clin Orthop Relat Res 212:142–154
21. Martinez AA, Herrera A, Cuenca J (2004) Marchetti nailing of humeral shaft delayed unions. Injury 35:257–263
22. McKee MD, Wild LM, Schemitsch EH et al (2002) The use of an antibiotic-impregnated, osteoconductive, bioabsorbable bone substitute in the treatment of infected long bone defects: early results of a prospective trial. J Orthop Trauma 16:622–627
23. Oh JK, Bae JH, Oh CW et al (2009) Treatment of femoral and tibial diaphyseal nonunions using reamed intramedullary nailing without bone graft. Injury 40:309–314
24. Paramasivan ON, Younge DA, Pant R (2000) Treatment of nonunion around the olecranon fossa of the humerus by intramedullary locked nailing. J Bone Joint Surg Br 82:332–335
25. Patel VR, Menon DK, Pool RD et al (2000) Nonunion of the humerus after failure of surgical treatment: management using the Ilizarov circular fixator. J Bone Joint Surg Br 82:977–983
26. Pugh DM, McKee MD (2003) Advances in the management of humeral nonunion. J Am Acad Orthop Surg 11:48–59
27. Reed LK, Mormino MA (2004) Functional outcome after blade plate reconstruction of distal tibia metaphyseal nonunions: a study of 11 cases. J Orthop Trauma 18:81–86
28. Ring D, Jupiter JB, Gulotta L (2003) Atrophic nonunions of the proximal ulna. Clin Orthop Relat Res 409:268–274
29. Ring D, Kloen P, Kadzielski J et al (2004) Locking compression plates for osteoporotic nonunions of the diaphyseal humerus. Clin Orthop Relat Res 425: 50–54
30. Sarmiento A, Burkhalter WE, Latta LL (2003) Functional bracing in the treatment of delayed union and nonunion of the tibia. Int Orthop 27: 26–29
31. Van Houwelingen AP, McKee MD (2005) Treatment of osteopenic humeral shaft nonunion with compression plating, humeral cortical allograft struts, and bone grafting. J Orthop Trauma 19:36–42
32. Weiss RJ, Montgomery SM, Ehlin A et al (2008) Decreasing incidence of tibial shaft fractures between 1998 and 2004: information based on 10,627 Swedish inpatients. Acta Orthop 79:526–533
33. Cierny G III, Zorn KE (1994) Segmental tibial defects: comparing conventional and Ilizarov methodologies. Clin Orthop Relat Res 301:118–123

Skeletal Reconstruction

14

Carmen Iglesias-Urraca

14.1 Introduction

Skeletal defects result more often from trauma but also may result from oncologic or infection. Additionally, traumatic injuries that have been treated with definitive fixation may subsequently develop a non-union requiring bony debridement, and as a result skeletal defect must be reconstructed.

The main objectives of fracture management are stabilisation, length maintenance, preservation of function and early rehabilitation. In the past, extensive skeletal defects were primarily managed by interposition of nonvascularised autografts and allografts in combination with external/internal fixation or by Ilizarov bone-lengthening technique. Because of narrow blood supply, these methods showed high rates of infection, non-union and early fracture. Ultimately, these methods were limited to segmental defects of less than 5 cm in length. Reconstructive microsurgery has opened new possibilities in skeletal reconstruction. Vascularised bone transplants provide excellent structural support while at the same time reducing the rates of infection or non-union and increasing the bone union and the functional outcome.

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14.2 Diagnosis

Injuries to the appendicular and axial skeleton are commonly encountered at most medical centres. Both plastic and trauma surgeons are called upon to treat these challenging patients. They are best served with the "orthoplastic" approach in a multidisciplinary setting [1]. This is the major challenge to improve result, the participation of many disciplines as orthopaedic and plastic surgeon, physical therapists, vascular surgeons, infectious disease physicians and the prosthetics [2].

One must consider (1) the nature of the defect, including its anatomic position and length, (2) other associated injuries of the ipsilateral or contralateral extremity, (3) concomitant trauma injuries, (4) the nature of the surrounding tissues, (5) the potential for a functional recovery, and (6) the cost associated with the reconstruction, both financial and social.

One of the key concerns in the reconstruction of the appendicular and axial skeleton is the blood supply to the bone graft. If a cancellous or cortical cancellous bone graft is planned, then it is the blood supply of the underlying wound bed that will be responsible for supplying the necessary blood supply to the graft. If there is a poor blood supply to the wound bed, the success of a nonvascularised bone graft is poor despite a meticulous surgical approach. In patients whom a vascularised bone graft is planned, there needs to be adequate inflow and outflow to achieve success. If there is any abnormality or nonpalpable pulses, the author's preference is to obtain an arteriogram or better an CT angiograhy.

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The other alternative to these patients is amputation. These patients must be carefully selected. Patients who elect reconstruction and limb salvage will require an increased number of operative procedures compared with those that choose amputation. The medical team must individualise the indications in function of the true outcomes possible.

14.3 Treatment and Surgical Technique

To maximise the potential for skeletal stability, one must understand the methods of reconstruction and the limitations of each approach. There are several methods of skeletal reconstruction: conventional cancellous or corticocancellous bone grafting, nonvascularised allografts, vascularised free flap transfer of a bone or a bone with associated soft tissue and distraction osteogenesis through the use of the Ilizarov technique. These methods are not mutually exclusive and may be combined to extend the capability of one modality alone.

14.3.1 Bone Grafting

Fresh autologous graft, particularly cancellous bone, has osteogenic properties provided by osteoinductive growth factors, osteogenic cells and structural scaffold. Autologous graft supports all aspects of bone regeneration (osteoinduction, osteoconduction and osteogenesis) at the recipient site and, as such, is considered superior in promoting bone healing [3]. Bridging large bone defects by avascular grafts involves creeping substitution with cells migrating from the well-perfused resection into an almost acellular matrix. This is related to the fact that osteoblasts are not able to survive in biological surroundings with low oxygen tension. Thus, the use of avascular grafts not only requires time but also bears the risk for complications, including bone atrophy, transplant fracture and non-union. Successful bone grafting is dependent upon the adequate vascularisation of the host's wound bed.

Traditionally, corticocancellous bone graft had been used for bony defects that are 5 cm or less in length. This technique requires a well-vascularised wound bed for bone grafting that is free of underlying infection and has adequate soft-tissue coverage.

The principles stabilised for Kazanjian [4] in the 1950s and still hold true today are the following: (1) The recipient site must have adequate blood supply to ensure the survival of the graft, (2) bone-to-bone contact must be established to facilitate creeping substitution, (3) there should not be any motion at the fracture site through the use of rigid fixation and (4) the wound bed must be free of infection. For defects of more than 5–6 cm, graft reabsorption prevents complete healing [5].

Masquelet et al. [6] described a technique for inducing the bioactive membrane. This technique has extended the diaphyseal defects for which cancellous bone grafting may be substituted with success. The basic tenets of wound preparation are radical debridement of devitalised tissue and delineation of the intercalary defect. If it is a concomitant soft-tissue defect, a free-flap reconstruction must be used to ensure the definitive soft-tissue reconstruction. A polymethylmethacrylate spacer is then placed into the defect in the first stage. The second stage is undertaken in 6–8 weeks when the spacer is removed. The membrane which is induced must be left in place. This membrane packs the cancellous bone graft. This membrane has been shown to have biological properties [7], including a rich vascular network, a synovial-like epithelial lining and a biologically active secretion of growth factors. Nonvascularised autografts are now harvested from the iliac crest. These bones have an abundant source of corticocancellous graft.

14.3.2 Distraction Osteogenesis and the Ilizarov Technique

The Ilizarov technique [8, 9] is a means of generating bony length through distract in osteogenesis as well as the capacity to generate additional soft tissue. It can be used for defects up to 15 cm and may be combined with free bone flaps or fasciocutaneous, muscle, and musculocutaneous flaps [10]. It can be used in non-unions, segmental bone loss, malrotation and congenital abnormalities. The technique requires the use of an external fixator that allows axial motion. The principal disadvantages are the following: time consuming, difficulty in tolerating the external fixator device and the local infection [11–13].

14.3.3 Allograft Reconstruction

Allografts are nonvascularised and lack any osteogenic potential. Their healing is slow, and their incorporation is never complete. Allografts may be intercalary or osteoarticular [14]. Union times can be as long as 23 months in the intercalary position and 12 months in the osteoarticular position. The success always depends on the surrounding soft tissue. To achieve better results, a well-vascularised tissue around the allograft is required. It is better to cover it with a well-vascularised flap. There is a failure rate of 14 % and a wide rate of complication (30 %), and these rates can decrease with a good cover technique [15–18].

The Capanna technique [19] is a mix between the allograft technique and the vascularised bone flaps. It takes the advantage of both allograft and free vascularised bone reconstruction. Intercalary allograft provides initial stability and mechanical strength, while the free vascularised bone allows integration, the capacity of bony remodelling and the long-term viability of the construct bony union [20]. The traditional technique includes the fibula free flap into the endomedular channel of the allograft with a canal to allow vessels get out the allograft. The "hemicapana" [21, 22] technique uses only a part of the allograft and permits much easier positioning of the pedicle to facilitate microanastomoses.

14.3.4 Vascularised Bone Grafting

Intercalary defects longer than 5 cm typically require free vascularised bone reconstruction. This technique has a significant advantage over the nonvascularised techniques. Free microvascular bone transfers are used to cover large defects [23]. The blood supply is preserved by anastomosing the vessels of the bone being transferred to the host's vessels. It is believed that preserving the arterial blood supply of the periosteum and endosteum enables primary healing and induces vital osteoblasts. Thus, the graft does not undergo necrosis and revascularisation takes place. Both the anastomosed pedicle and the support from the well-vascularised surrounding tissue ensures the success of the technique.

Factors to consider when choosing a bone flap are (1) the available pedicle length, (2) the available bone stock in terms of its length and thickness, (3) its osteogenic potential and (4) the difficulty of harvesting. Additionally, it must value the possibility of the addition of a skin paddle and/or muscle, the recipient's vessels and the osteosynthesis device. Donor sites include the iliac crest flap, fibular flap, rib flap and the medial femoral condyle corticoperiosteum flap.

14.3.4.1 Fibular Flap

Fibular flap has become the preferred source for vascularised bone grafts for the reconstruction of defects of the axial and the appendicular skeleton [24]. The fibula is well suited for the use as a free vascularised bone grafting, providing up to 26 cm of vascularised cortical bone with the ability to support angular and rotational stress and remodel and hypertrophy with graduated weight bearing in the postoperative period for intercalary defects. The blood supply of the diaphysis is based on an endosteal and musculoperiosteal component from the peroneal artery and vein. Only in a small number of patients is the peroneal artery dominant to supply blood to the lower extremity. The peroneus magna [25] artery may not be evident in the preoperative exam, but it can be encountered intraoperatively to avoid the transfer so as not to render the foot ischaemic. The double vascularity of the fibula with endosteal and periosteal vessels enhances the biology at the recipient site and improves healing.

Remodelling, incorporation and hypertrophy of the graft are depending on the immediate restoration of the vascular supply after anastomosis. The epiphyseal [26] of the fibula head is supplied by the anterior tibial artery. If the epiphyseal growth is needed, the anterior tibia must be included. If it is necessary physis and diaphysis, the anterior tibial and the peroneal vessels must be included in the flap pedicle.

It can be used in upper extremity reconstruction where the shape and size of the fibula is particularly favourable for the reconstruction of the humerus [26] and the forearm [27] bones. It can also be used in the lower leg as a single- or as a "double-barrel" shape [28]. In this case, the proximal segment is vascularised by endosteal and periosteal vessels and the distal one with the periosteal vessel. The fibula flap has a double vascularity, because of this it can be trisected into two struts that share the same pedicle. By this method, the effective cross-sectional area of the graft is duplicated. Jupiter et al. [29] who introduced this technique proposed osteotomy to be done at approximately the centre of the fibula with a continuous of the periosteum [30].

However, other authors prefer to osteotomise the fibula in unequal struts. The longer strut is doweled into the medullary cavity of the recipient bone, and the smaller inlay parallel to the recipient bone [31–33]. This technique is indicated in femur and proximal tibia reconstruction when the defect is shorter than 13 cm.

If there is any doubt of ankle stability following harvesting the fibula, a sindesmotic screw should be placed for additional stability of the ankle joint. Careful dissection must be taken to be aware of a peroneal magna artery [34]. Large series have demonstrated persistent long-term deficits after fibula harvest. They may have pain, ankle stability and/or weakness after harvesting the fibula [35]. Up to 11 % have persistent pain. The motor weakness decreases over time [36].

14.3.4.2 Scapular and Parascapular Flaps

They remain a viable source of adequate bone stock for reconstruction. The scapular osteocutaneous flap has a reliable vascular pedicle and permits about 11–13 cm length of bone from the lateral side of the scapula. This osseous segment is vascularised by the branches of the circumflex scapular vessels. The medial aspect of the scapula can be harvested, although this requires detaching the serratus, the teres major and the greater rhomboid muscles, and it has more donor morbidity. The latissimus and serratus muscle can be included on a single subscapular pedicle. This allows a greater versatility in designing flaps.

14.3.4.3 The Radial Forearm Flap

It provides a thin fasciocutaneous skin paddle that is 8–10 cm in length and 1–1.5 cm in width. The thickness does not allow it to be used for intercalary defects, except for the exception of the metacarpal or metatarsal defects. Another problem is the risk of radius fracture.

14.3.4.4 The Iliac Crest Flap

It was popularised in the 1980s [37]. Its vascular supply is based on the deep circumflex iliac artery. It has the advantage of being able to supply a 4×11 cm of bone with a skin paddle of 8×18 cm. One limit in intercalary defect is its curve. It is possible to perform osteotomies to get a more straight form. The problems are the risk of hernia (9 %) and the anaesthesia in the cutaneous lateral femoral nerve in the thigh. Persistent pain is also a problem in 8 % of the patients.

14.3.4.5 Periosteal Flaps

Periosteal and osteoperiosteal flaps from the medial femoral condyle flap are based in the descending geniculate artery, and they can be used with success in non-unions of the appendicular and axial skeleton. The vascularised medial femoral condyle flap can be harvested as an osteogenic periosteal flap and osteoperiosteal or a cutaneous osteoperiosteal flap depending on the need of reconstruction. Sakai et al. [38] subsequently described free vascularised thin, corticoperiosteal flaps based on the articular branch of the descending geniculate artery and vein [39, 40] or the superomedial genicular vessels that were used in the treatment of persistent non-unions of the humerus, ulna and metacarpals. Since that time, MFC grafts have been used in the successful treatment of non-unions of the clavicle [41], humerus [42], tibia, subtalar joint, mandible and scaphoid. Its principal indication is bone defects with a non-well-vascularised surrounding of less than 3 cm in length.

14.3.5 Clinical Indications

14.3.5.1 Trauma

Skeletal defects are a challenge especially when they are combined with soft-tissue loss. The question about whether to salvage or not the extremities is not solved. Gustilo IIIB and IIIC fractures are often associated with combined soft tissue and bone defects [43–45].

The basic principles for the reconstruction of these lesions, delineated by Godina in 1986, involve aggressive debridement of infected and devitalised tissue, primary stabilisation, early soft-tissue reconstruction and bone reconstruction. In these cases the surgeon must decide between one-time reconstruction and sequential reconstruction [46], first the soft tissue and then the bone.

Secondary defects may also result after wide excision of pathological tissue in case of septic or aseptic non-union. Nowadays specialised teams consider one-stage procedure. It is easier and time- and cost-effective, with better results and without more morbidity. It includes simultaneous bone and soft-tissue reconstruction, early bony stability, stimulation of bone union and decreased time for bone healing, prevention of soft tissue and vessel scarring and decreased rate of infection. There are several advantages of one-stage reconstruction [47]: (1) achievement of bone defect reconstruction at the same time as soft-tissue coverage, (2) prevention of adjacent soft-tissue and recipient vessel scarring and limitation of the quality of recipient vessels because of repeated tissue transfers, (3) avoidance of difficulty and risk of repeated microvascular tissue transfer, (4) early structural stability of the bone, (5) promotion of bone union, (6) success rate for resolving infection and (7) reduction of overall healing time of severe complex injuries of the lower extremities [48].

14.3.5.2 Non-union and Chronic Osteomyelitis

Non-union is defined as a complete cessation of the healing process after 6–9 months. Assuming that mechanical stability is optimal, an inadequate blood supply of the fracture site is considered as the primary contributor. Two conditions are required to establish union. One is the stability and the other is the biological stimulus for the callus to finish the healing process. In most cases there is bone atrophy, damage to the surrounding soft tissue and local infection.

Treatment of infected non-union and chronic osteomyelitis remains a challenge, mainly because of alterations in bacterial flora and appearance of resistant bacteria. Systemically delivered antibiotic cannot easily reach the septic area due to the presence of a biologically inactive bone surrounded by scarred tissue. In the presence of necrotic bone or foreign material, bacteria grow in biofilms, a barrier for antibiotics and the host's defence mechanisms, so radical debridement of the infected tissue is the mainstay of the treatment. These complex cases require adequate bone and soft-tissue debridement and bone and soft-tissue repair with osteocutaneous flaps, musculo-osteocutaneous flaps, corticoperiosteal flaps and cutaneous-corticoperiosteal flaps [48]. Adequate debridement is the key process in these cases, then chooses the ideal flap to achieve stability and soft-tissue reconstruction with a well-vascularised flap (Figs. 14.1, 14.2, 14.3, and 14.4).

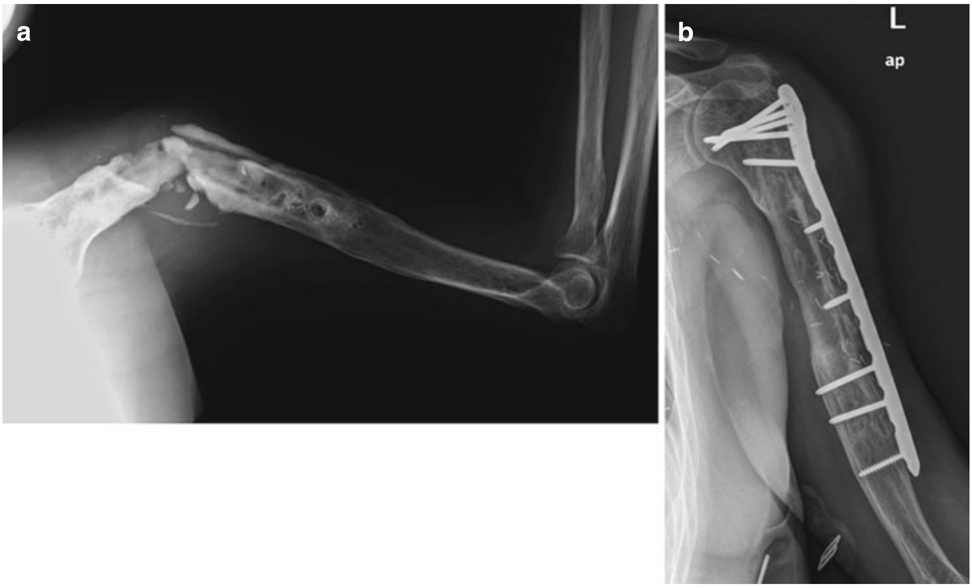

Fig. 14.1 Fibula flap to humerus reconstruction. It is paramount to perform a careful intercalary resection and also remodelling the fibula to mimic a humerus. (**a**) Preoperative radiograph. (**b**) Postoperative radiograph

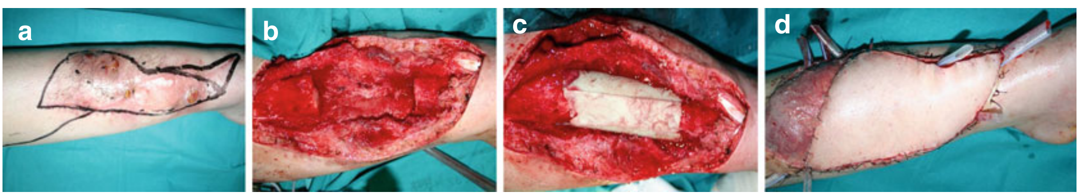

Fig. 14.2 Two-stage reconstruction of a tibial osteomyelitis. First stage: Aggressive debridement, spacer and soft tissue reconstruction with a latissimus dorsi flap. Intraoperative views (**a**–**d**)

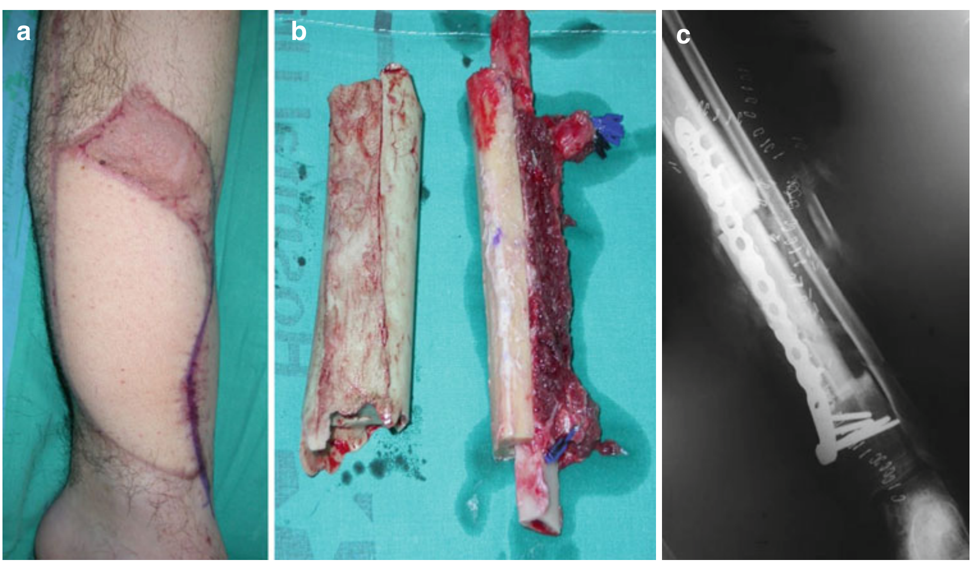

Fig. 14.3 Second stage of same case of Fig. 14.2: Capanna's technique with an allograft mixed with a free fibular flap. (**a**, **b**) Intraoperative views. (**c**) Postoperative radiograph

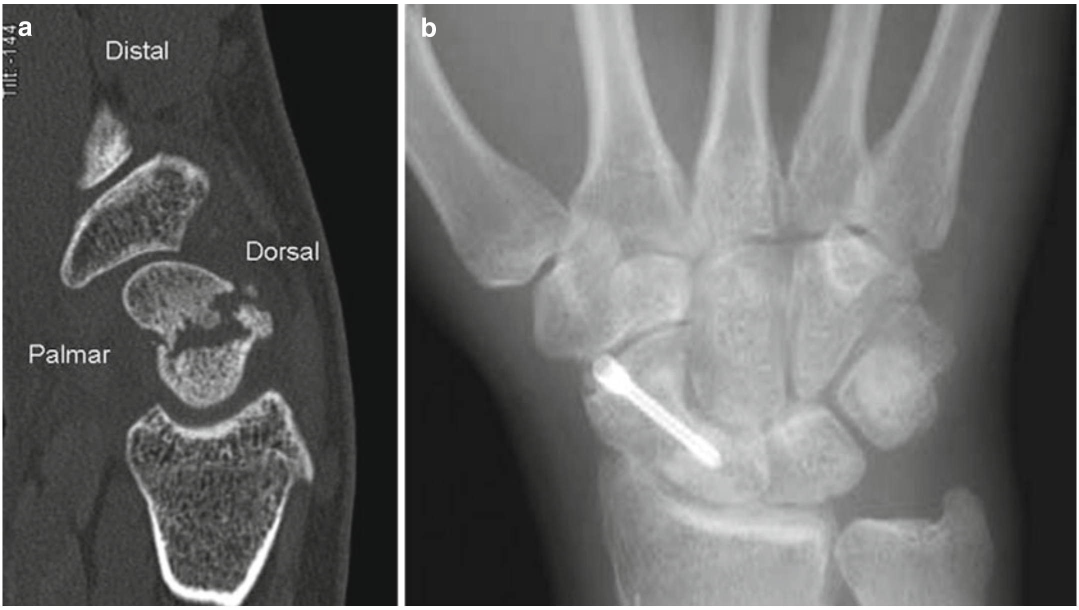

Fig. 14.4 Medial condyle flap to repair a scaphoid non-union. (**a**) CT preoperative view. (**b**) Postoperative radiograph

Conclusions

Skeletal reconstruction remains a challenging problem for both plastic and orthopaedic surgeons. Bone defects are usually the result of high-energy trauma, recalcitrant non-union, tumour resection or severe sepsis. The limb-sparing surgery is relatively new. The improved understanding of bone healing, infection and tumour biology, combined with the introduction of effective systemic and local antibiotics and neoadjuvant therapy, and the advance of biomaterials and endoprosthesis have bought the era of limb-sparing surgery of the extremities. In the past, skeletal defects were primarily managed by interposition of nonvascularised autografts and allografts. These methods had high rates of complications and were limited to defects of less than 5 cm in length. The reconstructive microsurgery has had an important impact in the ability to reconstruct skeletal defects by a vascularised bone transfer. It is important to understand how to approach skeletal defects and their algorithm of reconstruction.

References

1. Heitmann C, Levin LS (2003) The orthoplastic approach for management of the severely traumatized foot and ankle. J Trauma 54:379–390
2. Levin LS (1993) The reconstructive ladder. An orthoplastic approach. Orthop Clin North Am 24:393–409
3. Marino JT, Ziran BH (1952) Use of solid and cancellous autologous bone graft for fractures and nonunions. Orthop Clin North Am 41:15–26
4. Kazanjian V (1952) Bone transplanting to the mandible. Am J Surg 83:633–639
5. Stevenson S (1999) Biology of bone grafts. Orthop Clin North Am 30:543–552
6. Masquelet AC, Fitoussi F, Begue T et al (2000) Reconstruction of the long bones by the induced membrane and spongy autograft. Ann Chir Plast Esthet 45:346–353
7. Pelissier P, Masquelet AC, Bareille R et al (2004) Induced membranes secrete growth factors including vascular and osteoinductive factors and could stimulate bone regeneration. J Orthop Res 22:73–79
8. Ilizarov GA (1989) The tension-stress effect on the genesis and growth of tissues. Part I. The influence of stability of fixation and soft-tissue preservation. Clin Orthop Relat Res 238:249–281
9. Ilizarov GA (1989) The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. Clin Orthop Relat Res 239:263–285

10. Hollenbeck ST, Woo S, Ong S et al (2009) The combined use of the Ilizarov method and microsurgical techniques for limb salvage. Ann Plast Surg 62:486–491
11. Feldman DS, Shin SS, Madan S et al (2003) Correction of tibial malunion and nonunion with six-axis analysis deformity correction using the Taylor Spatial Frame. J Orthop Trauma 17:549–554
12. Fiebel RJ, Oliva A, Jackson RL et al (1994) Simultaneous free-tissue transfer and Ilizarov distraction osteosynthesis in lower extremity salvage: case report and review of the literature. J Trauma 37: 322–327
13. Lowenberg DW, Feibel RJ, Louie KW et al (1996) Combined muscle flap and Ilizarov reconstruction for bone and soft tissue defects. Clin Orthop Relat Res 332:37–51
14. Cheng EY, Gebhardt MC (1991) Allograft reconstructions of the shoulder after bone tumor resections. Orthop Clin North Am 22:37–48
15. Gebhardt MC, Flugstad DI, Spingfield DS et al (1991) The use of bone allografts for limb salvage in high-grade extremity osteosarcoma. Clin Orthop Relat Res 270:181–196
16. Mankin HJ, Gebhardt MC, Jennings LC et al (1996) Long-term results of allograft replacement in the management of bone tumors. Clin Orthop Relat Res 324:86–97
17. Ortiz-Cruz E, Gebhardt MC, Jennings LC et al (1997) The results of transplantation of intercalary allografts after resection of tumors. A long term follow up study. J Bone Joint Surg Am 79:97–106
18. Donati D, Di Liddo M, Zavatta M et al (2000) Massive bone allograft reconstruction in high-grade osteosarcoma. Clin Orthop Relat Res 377:186–194
19. Capanna R, Campanacci DA, Belot N et al (2007) A new reconstructive technique for intercalary defects of long bones: the association of massive allograft with vascularized fibular autograft. Long-term results and comparison with alternative techniques. Orthop Clin North Am 38:51–60
20. Moran SL, Shin AY, Bishop AT (2006) The use of massive bone allograft with intramedullary free fibular flap for limb salvage in a pediatric and adolescent population. Plast Reconstr Surg 118:413–419
21. Berrey BH Jr, Lord CF, Gebhardt MC et al (1990) Fractures of allografts. Frequency, treatment, and end-results. J Bone Joint Surg Am 72:825–833
22. Chang DW, Weber KL (2005) Use of a vascularized fibula bone flap and intercalary allograft for diaphyseal reconstruction after resection of primary extremity bone sarcomas. Plast Reconstr Surg 116:1918–1925
23. del Pinal F, Innocenti M (2007) Evolving concepts in the management of the bone gap in the upper limb. Long and small defects. J Plast Reconstr Aesthet Surg 60:776–792
24. Adani R, Delcroix L, Innocenti M et al (2004) Reconstruction of large post-traumatic skeletal defects of the forearm by vascularized free fibula graft. Microsurgery 24:423–429
25. Taylor GI, Wilson KR, Rees MD et al (1988) The anterior tibial vessels and their role in epiphyseal and diaphyseal transfer of the fibula: experimental study and clinical applications. Br J Plast Surg 41:451–469
26. Muramatsu K, Doi K, Ihara K et al (2003) Recalcitrant posttraumatic nonunion of the humerus: 23 patients reconstructed with vascularized bone graft. Acta Orthop Scand 74:95–97
27. Jupiter JB, Fernandez DL, Levin LS et al (2009) Reconstruction of posttraumatic disorders of the forearm. J Bone Joint Surg Am 91:2730–2739
28. Jones NF, Swartz WM, Mears DC et al (1988) The "double barrel" free vascularized fibular bone graft. Plast Reconstr Surg 81:378–385
29. Jupiter JB, Gerhard HJ, Guerrero J et al (1997) Treatment of segmental defects of the radius with use of the vascularized osteoseptocutaneous fibular autogenous graft. J Bone Joint Surg Am 79:542–550
30. Chen SH, Jeng SF, Liu HC (2003) Functional reconstruction of a massive defect in the two forearm bones. J Trauma 55:774–777
31. Chen MT, Chang MC, Chen CM et al (2003) Double-strut free vascular fibular grafting for reconstruction of the lower extremities. Injury 34:763–769
32. Campanacci M, Zanoli S (1966) Double tibiofibular synostosis for nonunion and delayed union of the tibia: end result review of one hundred seventy one cases. J Bone Joint Surg Am 48:44–56
33. Girdlestone GR, Foley WB (1933) Extensive loss of tibial diaphysis: tibiofibular grafting. Br J Surg 20:467–471
34. Duymaz A, Karabekmez FE, Vrtiska TJ et al (2009) Free tissue transfer for lower extremity reconstruction: a study of the role of computed angiography in the planning of free tissue transfer in the posttraumatic setting. Plast Reconstr Surg 124:523–529
35. Vail TP, Urbaniak JR (1996) Donor-site morbidity with use of vascularized autogenous fibular grafts. J Bone Joint Surg Am 78:204–211
36. Duffy GP, Wood MB, Rock MG et al (2000) Vascularized free fibular transfer combined with autografting for the management of fracture nonunions associated with radiation therapy. J Bone Joint Surg Am 82:544–554
37. Taylor GI, Townsend P, Corlett R (1979) Superiority of the deep circumflex iliac vessels as the supply for free groin flaps. Plast Reconstr Surg 64:595–604
38. Sakai K, Doi K, Kawai S (1991) Free vascularized thin corticoperiosteal graft. Plast Reconstr Surg 87: 290–298
39. Yamamoto H, Jones DB Jr, Moran SL (2010) The arterial anatomy of the medial femoral condyle and its clinical implications. J Hand Surg Eur Vol 35: 569–574
40. Choudry UH, Bakri K, Moran SL et al (2008) The vascularized medial femoral condyle periosteal bone flap for the treatment of recalcitrant bony nonunions. Ann Plast Surg 60:174–180
41. Fuchs B, Steinmann SP, Bishop AT (2005) Free vascularized corticoperiosteal bone graft for the treatment

of persistent nonunion of the clavicle. J Shoulder Elbow Surg 14:264–268
42. Hollenbeck ST, Komatsu I, Woo S et al (2011) The current role of the vascularized-fibular osteocutaneous graft in the treatment of segmental defects of the upper extremity. Microsurgery 31:183–189
43. MacKenzie EJ, Bosse MJ, Kellam JF et al (2002) Factors influencing the decision to amputate or reconstruct after high-energy lower extremity trauma. J Trauma 52:641–649
44. MacKenzie EJ, Bosse MJ, Kellam JF et al (2006) Early predictors of long-term work disability after major limb trauma. J Trauma 61:688–694
45. MacKenzie EJ, Bosse MJ, Pollak AM et al (2005) Long-term persistence of disability following severe lower-limb trauma. Results of a seven-year follow-up. J Bone Joint Surg Am 87:1801–1809
46. Hutson JJ, Dayicioglu D, Oeltjen JC et al (2010) The treatment of Gustillo grade IIIB tibial fractures with application of antibiotic spacer, flap, and sequential distraction osteogenesis. Ann Plast Surg 64:541–552
47. Yazar S, Lin C, Wei F (2004) One-stage reconstruction of composite bone and soft-tissue defects in traumatic lower extremities. Plast Reconstr Surg 114:1457–1466
48. Wood MB (1987) Upper extremity reconstruction by vascularized bone transfers: results and complications. J Hand Surg Am 12:422–427

15 Management of the Polytrauma Patient

Juan Carlos Rubio-Suárez

15.1 Introduction

Trauma is the leading cause of death in the 1- to 45-year-old age group, and it is the fourth cause of death in the general population. In 2010 there were 5.2 millions of deaths by polytrauma worldwide (10.3 % of deaths). It causes as sick leaves as heart disease and cancer together. Polytrauma patient or multiple injured patient is defined as one that has injuries in two or more organs, systems, or cavities of the body that jeopardized the patient's life. We can also define it as a syndrome or systemic disease that includes multiple traumatic injuries to various organ systems which can trigger a systemic inflammatory response and produce a secondary deterioration of vital organs and systems. HC Pape et al. define polytrauma as the condition in which the following criteria were fulfilled: injuries of at least two long bone fractures, or one life-threatening injury and at least one additional injury, or severe head trauma and at least one additional injury [1] (Fig. 15.1).

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15.2 Pathophysiology

In 1974, Trunkey and Lim [2] described that the mortality of the polytrauma patients can happen in three differentiated stages:

- Immediately after the accident: as a result of head injury or massive hemorrhage due to heart or large mediastinal vessel rupture [3]
- Between first and fourth hour after the accident: secondary to uncontrolled bleeding into thoracic, abdominal, or pelvic cavity
- Delayed death from the first week, due to sepsis or multiple organ failure

15.2.1 Lethal Triad

One of the most common and most serious complications in the polytrauma patient is hemorrhage. Blood loss leads to a decreased oxygen transport to the tissues. Hypoxemia triggers metabolic alterations that drive the body to a situation called lethal triad. This situation consists of:

- Acidosis: Bleeding can cause hypovolemic shock. In consequence, tissues will be poorly perfused and cellular metabolism will be altered causing a metabolic acidosis.
- Hypothermia: Body temperature decreases under 35 °C due to hypovolemic shock and hypoxemia. These factors alter the neural regulation of the temperature by the hypothalamus. Furthermore, the patient's exposure to room temperature and perfusion with cold liquids must be added.

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Fig. 15.1 Multiple injured patient

- Coagulopathy: The normal coagulation mechanism is altered by blood loss causing a consumption coagulopathy. This is coupled with metabolic acidosis, hypothermia, and mediators of inflammation, all of which alter the coagulation cascade.

15.2.2 Systemic Inflammatory Response Syndrome (SIRS)

In the polytrauma patients, the defense mechanisms are activated by hypoxia, acidosis, and tissue hypoperfusion especially in the liver, kidney, and lung. The defense mechanisms activated trigger a hyper-inflammatory response that is characterized by tachycardia (>90 bpm), tachypnea (>20 bpm), body temperature >38.5 °C, and leukocytosis [4]. The clinical consequences of the hyper-inflammatory response are:

- Acute respiratory distress syndrome (ARDS) [5]: It is caused by damage of the alveolar membrane. An increased capillary permeability allows passage of rich plasma proteins into the alveolar space and the interstitial space of the alveolar membrane. Impaired alveolar-capillary barrier alters the gas exchange and increases the capillary blood pressure. The final result is hypoxemia and heart failure [6].
- Multiple organ failure syndrome (MOFS): Lung damage is followed by progressive damage of other organs such as the liver, kidney, and, finally, the heart. All this is accompanied by a status of sepsis. The MOFS may be explained by the phenomenon of intestinal bacterial translocation. Hypovolemic shock results in splanchnic ischemia that alters the intestinal mucosa. This results in the passage of intestinal bacteria and inflammatory mediators into the portal circulation. From here, they are distributed throughout the body causing serious damage to vital organs [7].

15.3 Initial Management: Advanced Trauma Life Support (ATLS)

A quick and effective initial care to polytrauma patient significantly improves his prognosis. It is called "golden hour." An adequate protocol and a close coordination between different treatment stages are necessary. The initial management of the polytrauma patient goes through two phases:

15.3.1 Prehospital Trauma Life Support (PHTLS)

PHTLS is held in the crash place by emergency teams. Their performance is critical to the prognosis of the patient and consists of:

- Triage: It is a method of victim's selection and classification based on chances of survival, therapeutic needs, and available resources.
- Immediate life support: Following the ABCDE protocol, the emergency teams should take special care in keeping a permeable airway and effective breathing, treating the hypovolemic shock, bleeding control, and adequate immobilization. Then, patient must be taken immediately to the nearer trauma center, decreasing the time of attention in the crash (scoop and run).
- Information and communication: Emergency team should obtain as much information as possible about patient medical history as well as accident characteristics. The obtained information must be communicated to the hospital prior to the patient transfer.

15.3.2 Advanced Trauma Life Support (ATLS) in the Hospital

The polytrauma patient management passes through three phases:

- Primary survey [8]: ABCDE protocol must be followed:

  A (*Airway*): Patency of the airway must be checked discarding the existence of foreign bodies, facial fractures, or laryngeal or tracheal injuries. The most common cause of airway obstruction is dropping of the tongue backward in unconscious patient. In case of obstruction of the airway and in patients with GCS <8, the isolation of the airway by endotracheal intubation or emergency cricothyroidotomy would be indicated. Special care must be taken with cervical spine. All trauma patients should be under suspicion of a cervical lesion. Any maneuver to restore the airway should be performed with cervical spine control.

  B (*Breathing*): Pulmonary, chest wall, and diaphragm functions are necessary to get an adequate breathing. If breathing is insufficient, one of these situations should be suspected:

- Tension pneumothorax: This situation requires immediate decompression by needle into second intercostal space midclavicular line or chest tube in 5th intercostal space.
- Flail chest: Require mechanical ventilation.
- Open pneumothorax: Treatment is airtight closure of the defect and drainage by chest tube.
- Massive hemothorax: It must be drained by a thoracic tube and hemorrhage controlled. If bleeding is greater than 1,500 cc initially or more than 200 cc/h during 2 h, exploratory thoracotomy may be necessary.

  C (*Circulation*): Hemodynamic state of the patient must be checked. There are four parameters to assess: consciousness, skin color and temperature, pulse, and blood pressure. If they are altered, hypovolemic shock should be suspected. The main cause of hypovolemic shock is severe hemorrhage so we must look for bleeding points. Hemorrhage may be:

- External hemorrhage: Especially in limbs. They can be controlled by hemostatic forceps or tourniquet.
- Internal or hidden hemorrhage: They used to be in thoracic, abdominal, or pelvic cavities. We must suspect its existence in all patients with hypovolemic shock and no visible bleeding.

In all patients with hypovolemic shock, two peripheral veins should be channeled, and then volume replacement will be introduced administering crystalloid liquids (ringer lactate) and isogroup blood.

Table 15.1 Glasgow Coma Score (GCS)

Eye opening		Verbal response		Motor response	
Spontaneous	4	Oriented	5	Obeys orders	6
To order	3	Confused	4	Localized pain	5
To pain	2	Inappropriate	3	Withdrawal to pain	4
No response	1	Incomprehensible	2	Abnormal flexion	3
		No response	1	Extension	2
				No response	1

Fig. 15.2 Gastric tube in a patient with facial injury

D (*Disability*): It consists of neurological evaluation exploring the level of consciousness, motor focality, and size and reactivity of pupils. The Glasgow Coma Score (GCS) is an excellent method to establish the neurological status in a simple and fast way (Table 15.1).

E (*Exposure*): The patient should be completely naked for proper exploration. However, we must be careful to avoid hypothermia so the emergency room shall be maintained at a suitable temperature, the patient should be covered, and intravenous fluids should be warmed before administration.

Other procedures:

- Nasogastric tube: In order to prevent gastric distension and aspiration pneumonia. Especial care must be taken in patients with facial injury (Fig. 15.2).
- Bladder catheterization: It is useful to establish diuresis control and avoid bladder distension. It should not be placed in suspected urethral disruption (Fig. 15.3).
- Monitoring: Permanent information of the heart rate, blood pressure, ECG, and pulse oximetry.
- Body CT scan: A complete radiological study by full body CT scan with contrast allows us to know those injuries that endanger the patient's life as a prelude to their urgent treatment.
- Secondary survey [9]: Once the patient is stabilized, a more detailed physical examination is mandatory to get an accurate diagnosis. It is useful to follow a systematic exploration by such as head and neck, thorax, abdomen, pelvis, spine, upper extremities, and lower extremities. At this stage, radiographs of areas with suspected injury will be taken.

Fig. 15.3 Blood in meatus. Urethral disruption suspected

Table 15.2 Revised Trauma Score (RTS)

Parameter	Value	Score
Respiratory frequency (bpm)	10–29	4
	>30	3
	6–9	2
	1–5	1
	0	0
Systolic blood pressure (mmHg)	>90	4
	76–89	3
	50–75	2
	1–49	1
	0	0
Glasgow coma score	13–15	4
	9–12	3
	6–8	2
	4–5	1
	3	0

Table 15.3 Abbreviated Injury Scale (AIS) of the chest trauma

Rib fracture	1
Fracture of 2–3 ribs	2
Lung contusion Unilateral H'/P' – thorax	3
Bilateral H'/P' – thorax Flail chest	4
Aortic laceration	5

15.4 Rating Scales in the Trauma Patient

They are mathematical tools for scoring the severity and prognosis of a given patient in a numerical scale. There are two types of scales: physiological scales and anatomic scales.

15.4.1 Physiological Scales

They are rating scales for prehospital use. The most widely used is the Revised Trauma Score (RTS) (Table 15.2) which employs three physiological parameters: Glasgow Coma Score (GCS), breath frequency (BF), and blood pressure (BP). The score is calculated through the following mathematical expression: 0.93(GCS) + 0.73(BF) + 0.29(BP). Lower score, lower probability of survival.

15.4.2 Anatomic Scales

The most widely used is Injury Severity Score (ISS). It is based on the list of Abbreviated Injury Scale (AIS) (Table 15.3) that divides the body in six different regions: (1) head and neck, (2) face, (3) thorax, (4) abdomen, (5) limbs, and (6) skin. A value is given to each of the regions in accordance with the severity of the injury. ISS is calculated by summing the squares of the three highest AIS that are not in the same region. To prevent undervaluation of serious injuries in the same region, the New Injury Severity Score (NISS) was created. NISS is calculated by summing the squares of the three highest values of AIS regardless of the anatomic region.

15.5 Decision Making in the Management of the Skeletal Injuries of the Polytrauma Patient

Management of the skeletal injuries in the polytrauma patient is a dynamic process that should be carried out according to the physiological situ-

Table 15.4 Physiological values to determine the clinical situation of a polytrauma patient

		Stable	Borderline	Unstable	In extremis
Hypovolemia	Systolic blood pressure (mmHg)	>100	80–100	60–80	<60
	Units of blood transfused	0–2	2–5	5–15	>15
	Lactate (mmol/l)	<2.5	2.5	>2.5	>5
	Base deficit (mmol/l)	Normal	<6	<8	>8
	Loss blood (%)	<15	15–30	30–40	>40
Coagulation	Platelets	>110,000	90,000–110,000	70,000–90,000	<70,000
	Factor II, V (%)	Normal	70–80	50–70	<50
	Fibrinogen (mg/ml)	>2	1–2	<1	Undetectable
Temperature	T °C	>34	32–34	30–32	<30
Soft tissue injury	Lung function (Pa = 2/ FiO_2)	350–400	300–350	200–300	<200
	Chest injury (AIS)	1	2–3	3–4	5
	Pelvic fracture (AO/ ASIF)	A–B1	B2–B3	B3–C1	C2–C3

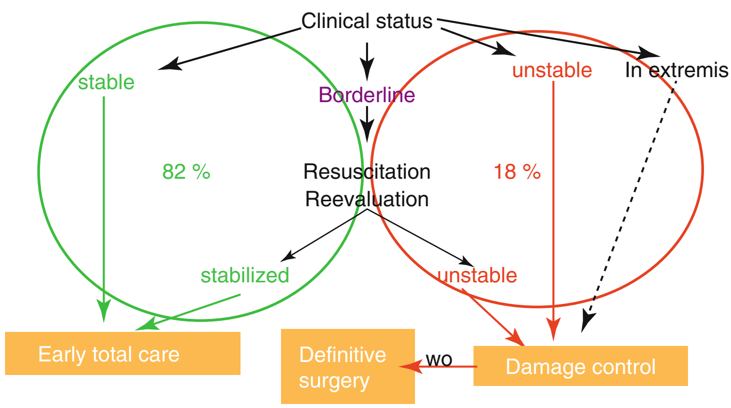

Fig. 15.4 Decision algorithm in polytrauma management

ation of the patient. We must consider the impact that the treatment of the fractures can have on the patient (second hit) [10]. What we must do is clear: stabilize immediately the fractures. How we can do it depends on patient situation. We have two options:

- Fix the fractures in a provisional, fast, and less aggressive way (damage control orthopedics).
- Fix the fractures in a definitive but slow and more aggressive way (early total care).

To make the decision, we must know the physiological condition of the patient. For this we use a series of clinical and analytical parameters that we use to classify patients into four physiological conditions: stable, unstable, borderline, and in extremis (Table 15.4). This classification allows us to decide the strategy according to a therapeutic algorithm (Fig. 15.4).

15.5.1 Damage Control (DCO) Surgery

The DCO goals are fast resuscitation, bleeding control, pain relief, and minimize the second hit. DCO surgery includes external fixation of pelvic and long bone fractures, fasciotomies, debridement and stabilization of open fractures, and reduction of joint dislocations (Fig. 15.5). DCO change to final internal fixation should be performed when the patient's situation permits. There are several stages in the evolution of severe polytrauma (Table 15.5). Definitive surgery should be made between 5th and 10th days, during the window of opportunity. This interval of time is when the patient's physiological conditions are optimal to support aggressive surgery [11].

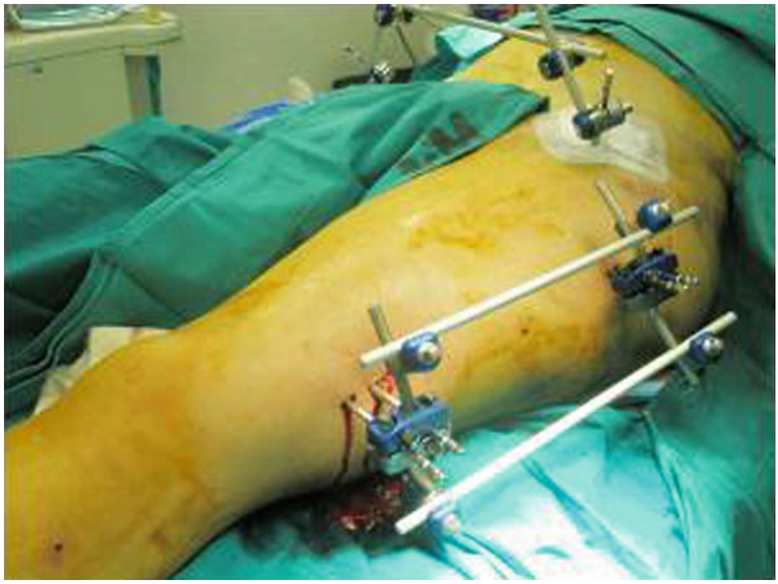

Fig. 15.5 Damage control surgery in unstable polytrauma patient

Table 15.5 Chronogram of the polytrauma evolution

Time	Physiological status	What to do?
Day 1	Resuscitation response	Save the life. CDO
Day 2–4	Hyper inflammation	Life support. Reevaluation
Day 5–10	Window of opportunity	Definitive surgery
Day 11–20	Immunosuppressant	No surgery
Day 21–…	Repair phase	Reconstructive surgery

15.5.2 Early Total Surgery

ET surgery is indicated in stable or borderline stabilized patient. It should be performed within 24 h after trauma and always in trauma centers with adequate human and material resources. Open reduction and internal fixation will be made according to the principles of osteosynthesis for each type of fracture.

15.6 Special Situations in Polytrauma Patients

15.6.1 Head Injury

Polytrauma patients with associated head injury require special consideration. Classification according to physiological conditions is not valid in these patients. ET in a stable patient with severe head injury may be deleterious for the intracranial pressure and the brain oxygenation. For an adequate management, we can follow these strategies [12]: ET in stable patients with GCS 14–15 and normal brain CT scan; DCO in stable patients with GCS < 9 and GCS 9–14 with abnormal brain CT scan; change DCO to definitive internal fixation when GCS increases to 12 or more; when the patient remains in coma but keeps stable values of intracranial pressure (<20 mmHg) and cerebral perfusion pressure (>80 mmHg) longer than 48 h.

15.6.2 Chest Injury

Early intramedullary nailing in the first 48 h is associated with a better functional outcome. However, it may cause some degree of lung damage. The main reasons for this are fat embolism syndrome [13] and respiratory distress due to the inflammatory response secondary to bleeding during surgery. For this reason, multiple trauma patients associated with thoracic trauma and long bone fractures deserve special consideration [14].

Stable polytrauma patient associated with thoracic trauma presents a thoracic AIS 1 or 2 and lung fraction (PaO_2/FiO_2) 350–400. So these patients may be managed by unreamed intramedullary nailing with no increased risk at respiratory distress [15].

In contrast, polytrauma patients classified as borderline present a lung function lower than that of stables' (300–350) and a lung AIS 2–3, so immediate nailing of long bone fractures may result in further lung damage [16, 17].

In summary, multiple trauma patients with thoracic trauma, if they are stable, can be subjected to early nailing of long bone fractures without increasing the risk of respiratory distress. However, multiple trauma patients with thoracic trauma presenting instability or borderline criteria should be initially treated by damage control surgery to decrease the risk of associated lung damage.

15.6.3 Spinal Injury

Spinal injury associated with multiple trauma has special characteristics. It may be undiagnosed. Furthermore, a poor handle of the patient or incorrect immobilization can trigger a neurological damage that previously did not exist (3–25 %). We should keep in mind that head injuries are frequently associated with cervical spine fractures and thoracic and abdominal injuries are associated with thoracic-lumbar spine fractures in a high percentage of cases. And we should not forget that spine fractures may be affecting two different segments in 5–20 % of cases. For all these reasons, a complete and adequate exploration of the spine, including CT scan and MRI as possible, should be carried out in all trauma patients.

15.6.3.1 Cervical Spine

C1 and C2 fractures produce neurological damage in 16 % of cases. When they are very displaced, they may cause death. The rest of fractures must be properly immobilized and subsequently surgically stabilized when the patient is stable. C3 to C7 fractures can produce neurological damage in higher percent of cases. In the polytrauma patient, all fractures should be initially immobilized, and the dislocations reduced and provisionally immobilized. Indications for surgery are recovery of spinal alignment, unstable lesions, neurological damage, and open fractures.

15.6.3.2 Thoracolumbar Fractures

Thoracolumbar fractures may be divided in six distinct patterns based on the three-column concept [18]. Urgent surgery is indicated only in the stable patient with progressive neurological injury which. In this case, we will make a decompression and immediate stabilization. Compression fractures with < 50 % wedging and stable burst fractures may be managed by conservative means. Delayed surgery is indicated in compression fractures with > 50 % wedging, unstable burst fractures, Chance's fracture, and fracture dislocation.

15.6.4 Open Fractures

Open fractures in multiple injured patients follow the same principles of management for fractures with soft tissue damage, that is to say, antibiotics [19], wash and debridement [20], and special care of the soft tissues [21]. Fracture stabilization should be made considering the general situation of the patient and soft tissue injury. In stable patient with little soft tissue damage or possibility for immediate coverage, definitive internal fixation can be made [22]. In most cases, however, damage control surgery by external fixation is the best option.

15.6.5 Compartment Syndrome

The diagnosis of compartment syndrome is primarily clinical. An exaggerated pain in the affected limb that increases with passive movements of the fingers or toes and unyielding with morphine should put us on alert. Measuring the pressure in the muscle compartments can be useful if we apply the following formula: middle blood pressure – intracompartmental pressure < 40 mmHg.

In the multiple injured patients, the diagnosis is difficult because of the low level of awareness that masks the pain and low blood pressure that affects the calculation of the differential pressure. In these cases the alert level should be over, and we have to react to the slightest suspicion [23]. The best treatment is the prophylaxis. It consists of opening all compartments by wide fasciotomy before irreversible complications are present.

Conclusions

Trauma is the leading cause of death in the 1- to 45-year-old age group, and it is the fourth cause of death in the general population. In 2010 there were 5.2 millions of deaths by polytrauma worldwide (10.3 % of deaths). One of the most common and most serious complications in the polytrauma patient is hemorrhage. Blood loss leads to a decreased oxygen transport to the tissues. Hypoxemia triggers metabolic alterations that drive the body to a situation called lethal triad: acidosis, hypothermia, and coagulopathy.

In the polytrauma patients, the defense mechanisms are activated by hypoxia, acidosis, and tissue hypoperfusion especially in the liver, kidney, and lung. The defense mechanisms activated trigger a hyper-inflammatory response that is characterized by tachycardia (>90 bpm), tachypnea (>20 bpm), body temperature > 38.5 °C, and leukocytosis [4]. The clinical consequences of the hyper-inflammatory response are acute respiratory distress syndrome (ARDS) and multiple organ failure syndrome (MOFS).

The initial management of the polytrauma patient goes through two phases: prehospital trauma life support (PHTLS) and advanced trauma life support (ATLS) in the hospital. ATLS protocol consists of three phases: primary survey (A, B, C, D, E), secondary survey, and definitive treatment of the injuries.

There are mathematical tools for scoring the severity and prognosis of the trauma patient in a numerical scale. There are two types of scales: physiological scales (RTS) and anatomic scales (NISS).

Management of the skeletal injuries in the polytrauma patient is a dynamic process that should be carried out according to the physiological situation of the patient. We must consider the impact that the treatment of the fractures can have on the patient (second hit). What we must do is clear: stabilize immediately the fractures. How we can do it depends on patient situation. We have two options: damage control surgery or early definitive surgery. Stable polytrauma patients with associated head injury require special consideration. In contrast, trauma patients with thoracic trauma, if they are stable, can be subjected to early nailing of long bone fractures without increasing the risk of respiratory distress.

Spinal injury associated with multiple trauma has special characteristics. It may be undiagnosed. Furthermore, a poor handle of the patient or incorrect immobilization can trigger a neurological damage that previously did not exist. A complete and adequate exploration of the spine, including CT scan and MRI as possible, should be carried out in all trauma patients.

Open fractures in multiple injured patients follow the same principles of management for fractures with soft tissue damage. In most cases, damage control surgery by external fixation is the best option.

The diagnosis of compartment syndrome is primarily clinical. In the multiple injured patients, the diagnosis is difficult because of the low level of awareness that masks the pain and low blood pressure that affects the calculation of the differential pressure. In these cases the alert level should be over, and we have to react to the slightest suspicion.

References

1. Papea HC, Zellea B, Lohsec R et al (2006) Evaluation and outcome of patients after polytrauma-can patients be recruited for long-term follow-up? Injury 37:1197–1203
2. Trunkey DD, Lim RC (1974) Analysis of 425 consecutive trauma fatalities. J Am Coll Emerg Phys 3:368–371
3. Pfeifer R, Tarkin IS, Rocos B et al (2009) Patterns of mortality and causes of death in polytrauma

patients- has anything changed? Injury 40: 907–911
4. Botha AJ, Moore FA, More EE et al (1995) Early neutrophil sequestration after injury: a pathogenic mechanism for multiple organ failure. J Trauma 39: 411–417
5. Ashbaugh DG, Bigelow DB, Petty TL et al (1967) Acute respiratory distress in adults. Lancet 2: 319–323
6. Ware L (2006) Pathophysiology of acute lung injury and the acute respiratory distress syndrome. Semin Respir Crit Care Med 27:337–349
7. Tsukamoto T, Chanthaphavong RS, Pape HC (2010) Current theories on the pathophysiology of multiple organ failure after trauma. Injury 41:21–26
8. Driscoll P, Skinner D (1996) Initial assessment and management I: primary survey. In: ABC of major trauma, 2nd edn. BMJ, London, pp 1–5
9. Driscoll P, Skinner D (1996) Initial assessment and management- II: secondary survey. In: ABC in major trauma, 2nd edn. BMJ, London, pp 6–10
10. Moore FA, Moore EE (1995) Evolving concepts in the pathogenesis of postinjury multiple organ failure. Surg Clin North Am 75:257–277
11. Pape HC, Giannoudis PV, Kretek C et al (2005) Timing of fixation of major fractures in blunt polytrauma: role of conventional indicators in clinical decision making. J Orthop Trauma 19:551–562
12. Flierl MA, Stoneback JW, Beauchamp KM et al (2010) Femur shaft fracture fixation in head-injured patients: when is the right time? J Orthop Trauma 24:107–114
13. Kontakis GM, Tossounidis T, Weiss K (2006) Fat embolism: special situations- Bilateral femoral fractures and pathologic femoral fractures. Injury 37S:S19–S24
14. Harwood PJ, Giannoudis PV, van Griesven M et al (2005) Alterations in the systemic inflammatory response after early total care and damage control procedures for femoral shaft fracture in severely injured patient. J Trauma 58:446–452
15. Weninger P, Figl M, Spitaler R et al (2007) Early reamed intramedullary nailing of femoral fractures is safe in patients with severe thoracic trauma. J Trauma Injury Infect Crit Care 62:692–696
16. Norris BL, Patton WC, Rudd JN et al (2001) Pulmonary dysfunction in patients with femoral shaft fracture treated with intramedullary nailing. J Bone Joint Surg Am 83:1162–1168
17. Hildebrand F, Giannoudis PV, Griensven M et al (2005) Management of polytraumatized patients with associated blunt chest trauma: a comparison of two European countries. Injury 36:293–302
18. Denis F (1983) The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine 8:817–831
19. Gosselin RA, Roberts I, Guillespie WJ (2004) Antibiotics for preventing infection in open limb fractures. Cochrane Database Syst Rev (1):CD003764
20. Werner CML, Piermont Y, Pollak AN (2008) The urgency of surgical debridement in the management of open fractures. J Am Acad Orthop Surg 16: 369–375
21. Zalavras CG, Marcua RE, Levin S et al (2007) Management of open fractures and subsequent complications. J Bone Joint Surg Am 89:884–895
22. Giannoudis PV, Papakostidis C, Roberts C (2006) A review of the management of open fractures of the tibia and femur. J Bone Joint Surg Br 88:281–289
23. Olson SA, Glasgow RR (2005) Acute compartment syndrome in lower extremity musculoskeletal trauma. J Am Acad Orthop Surg 13:436–444

Surgical Treatment of Osteoporotic Knee Fractures

16

E. Carlos Rodríguez-Merchán

16.1 Introduction

A knee fracture is defined "osteoporotic" if it is caused by a low-energy trauma only, that is, a fall from standing height or less [1]. Kannus et al. [1] predicted fracture development until the year 2030 by a regression model, which took into account the predicted changes in the fracture incidences and population at risk. The number and incidence (per 100,000 persons) of osteoporotic knee fractures in women aged ≥60 years clearly increased during the study period, from 218 (number) and 55 (incidence) in 1970 to 685 and 113 in 1999. Even after age adjustment, the incidence of women's fractures showed a clear increase, from 59 in 1970 to 105 in 1999. If this trend continues, there will be about 2.5 times more osteoporotic knee fractures in women in the year 2030 than there were in 1999. In men aged ≥60 years, the annual number of fractures and its changes were clearly smaller (77 in 1970 vs. 138 in 1999), and the fracture incidence did not show consistent trend changes over time (30 in 1970 vs. 34 in 1999). Kannus et al. [1] concluded that in elderly women the number of osteoporotic knee fractures showed a rise with a rate that could not be explained merely by demographic changes, and, therefore, preventive measures are needed to control this development.

Osteoporotic fractures can be a major cause of morbidity. A study demonstrated a negative association between osteoporotic fractures and health-related quality of life in both women and men [2].

Studies of the association between the presence of osteoarthritis (OA) and the risk of osteoporotic fractures have produced conflicting results. Arden et al. [3] found that despite having increased bone mineral density (BMD) of 5 %, subjects with hip OA had a significantly increased risk of fracture compared to controls. These data suggest that the increased risk of fracture in subjects with OA of the hip is most likely to be due to mechanical and locomotor factors, such as the risk of falling.

Liu et al. evaluated the role of LISS (less invasive stabilization system) in osteoporotic fractures around the knee [4]. The results indicated the LISS system is perfect but by no means unique in the treatment of osteoporotic fractures around the knee. The fixation was adequate enough to maintain alignment and obtain union with a low incidence of complications [4].

The fundamental issues of poor bone quality, poor hosts, and associated medical comorbidities make treating osteoporotic fractures about the knee in elderly patients difficult both in terms of the decision-making process and the chosen surgical technique [5].

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16.2 Supracondylar Femur Fractures

In a study, supracondylar femur fractures in severely osteoporotic patients (average age, 82 years) were treated with a 95° supracondylar plate and dynamic compression screw supplemented with intramedullary methyl methacrylate and massive cancellous bone graft harvested from the distal femoral metaphysis [6]. Interfragmentary compression and rigid fracture fixation were obtained in all cases with the use of the ASIF (Association for the Study of Internal Fixation) compression device. Patients were allowed early protected weight bearing without external immobilization. At follow-up observation (average, 2 years), bony union was seen in all cases, and knee flexion averaged 100°. There were no malunions or cases of implant failure. Complications included two early postoperative deaths and three femur fractures above the plate. The ASIF compression device was effective in rapidly restoring patient mobility while avoiding the complications of implant failure.

A retrograde supracondylar nail can also be used for the management of fractures of the distal femur in elderly patients. In a study, 18 fractures of the distal femur in 18 patients were treated with retrograde titanium supracondylar nails [7]. Sixteen patients with a median age of 83 years were reviewed. All 16 fractures were classified as extra-articular type A according to the ASIF classification. The average operative time was 58 min. Follow-up ranged between 4 and 35 months. Fifteen fractures (94 %) united in an average duration of 3.5 months. The average range of motion achieved at the knee was 100°. There were no implant failures, knee sepsis, or wound healing problems. One nonunion and two stress fractures of the femur above the nail were the main complications in this series. Retrograde titanium supracondylar nail is a useful alternative implant for the management of the osteoporotic fractures of the distal femur particularly the extra-articular AO type A fracture in elderly patients [7].

Intramedullary nail locking bolts often fail to gain purchase or cut out in osteoporotic bone. Ito et al. [8] performed standardized simulated comminuted supracondylar femoral fractures (segmental defect) in fresh-frozen paired osteoporotic (BMD, bone mineral density <200 mg/cm^3) human cadaveric femurs that were stabilized with a retrograde unreamed distal femoral nail and distally interlocked with conventional locking bolts or a bladelike device. The distal portions of the fixator-bone constructs were tested under axial load, and the stiffness and strength were compared. Their main results showed that interlocking with a bladelike device was 41 % stiffer and 20 % stronger than that with conventional locking bolts. All posttesting radiographs showed compaction of the cancellous bone distal to the interlocking devices. Even after nail displacements of 12 mm, only a few locking bolts were plastically deformed, and no bladelike device showed gross plastic deformation. The fixator-bone construct withstood higher forces before failure in osteoporotic cancellous bones [8].

Since 1992, Ingman [9] developed an implant in which the distal (condylar) screws had a diagonal configuration so that the screws can be closer to the distal end of the nail, allowing more distal fractures to be fixed. It also utilized the denser bone of the posterior condyles for more secure fixation in osteoporotic patients. The new implant was used for 24 extra-articular fractures during a 3-year period and for 14 articular fractures from a 6-year period. There was no significant difficulty with obtaining fixation in very distal fractures and in osteoporotic bone. Early weight bearing was allowed in those with extra-articular fractures. All fractures united within 3 months except one which required a bone graft (but no revision of implant) at 6 months. Average knee flexion at final follow-up was 100° for extra-articular fractures and 105° for articular fractures. Complications included quadriceps adhesions requiring further surgery in two patients who had open fractures and malunion in one patient who had an early design of the implant and a 4.5 mm condylar screw broke. Nine patients required late removal of condylar screws due to local soft tissue irritation.

Distal femoral fractures largely occur as osteoporotic fractures in the elderly population, including periprosthetic fractures above a TKA [10]. Operative fixation options include open reduction and internal fixation (Fig. 16.1), percutaneous

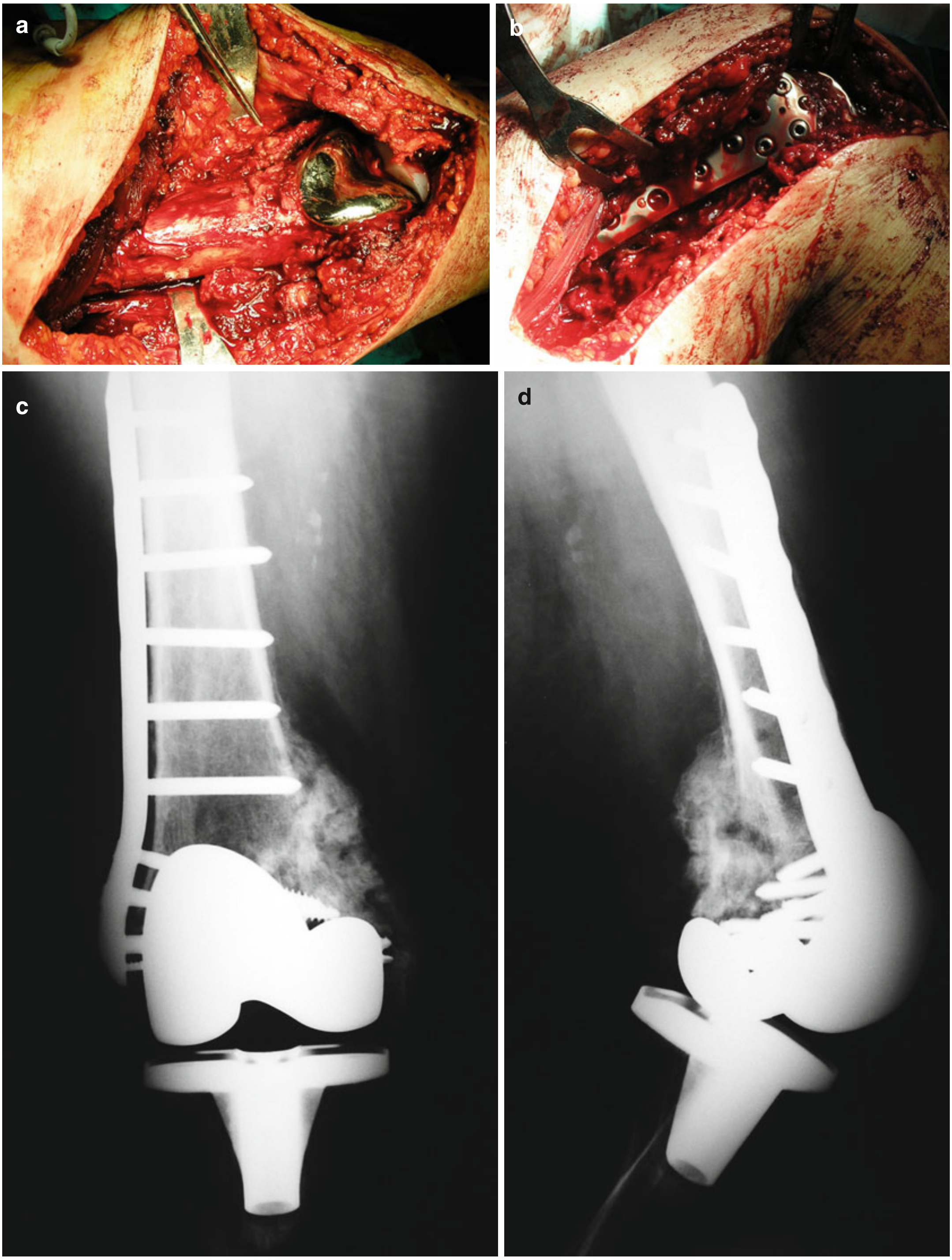

Fig. 16.1 Periprosthetic osteoporotic fracture above a TKA in an elderly patient. Operative fixation was performed by open reduction and internal fixation, with a satisfactory result (bone healing): (**a**) anteroposterior intraoperative view of the periprosthetic fracture. (**b**) Lateral intraoperative view after fixation of the fracture. (**c**) Anteroposterior radiograph 6 months later. (**d**) Lateral radiograph 6 months after bone fixation

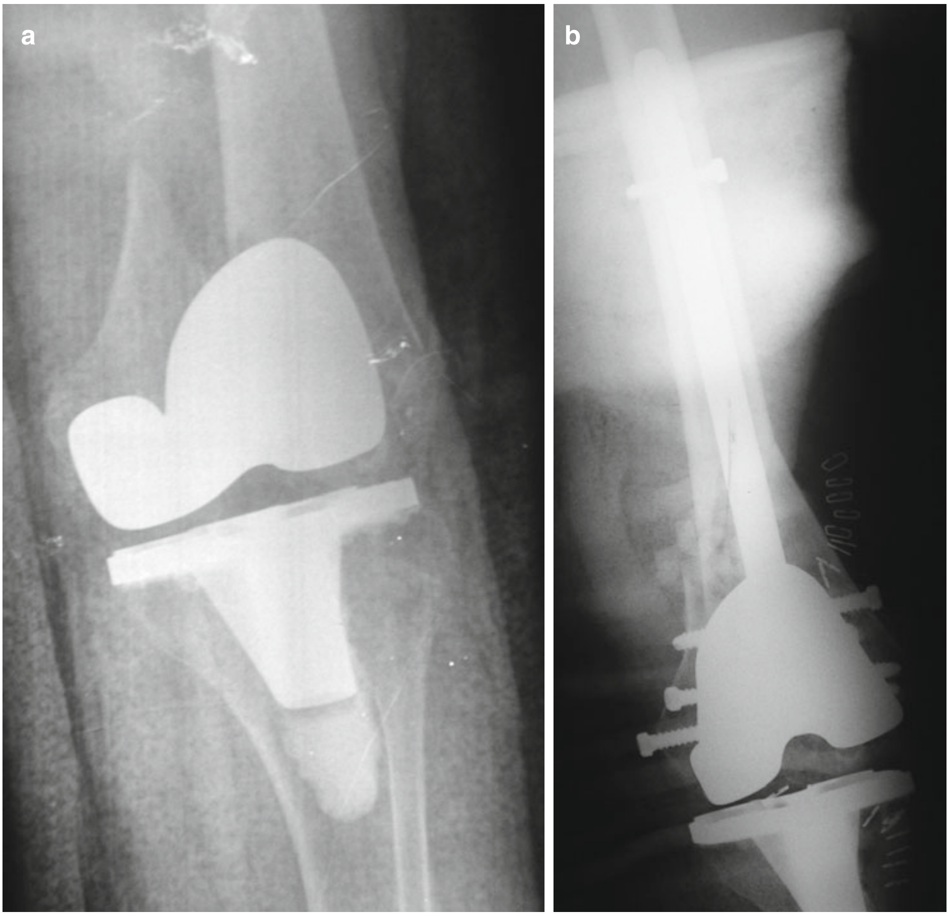

Fig. 16.2 Supracondylar osteoporotic fracture of the femur in another elderly patient. Operative fixation was performed by retrograde locked intramedullary (IM) nailing, with a satisfactory result: (**a**) anteroposterior radiograph of the fracture. (**b**) Anteroposterior radiograph after IM nailing

submuscular plating techniques, intramedullary nailing (Fig. 16.2), or bridge plating. As with any fracture, treatment choice must be individualized according to the nature of the injury, bone quality, and patient demand. Regardless of treatment method, goals include restoration of articular congruity, anatomical length, rotation, and axial alignment while establishing adequate fixation to initiate early and unrestricted range of motion.

Cavusoglu et al. [11] assessed the effectiveness of a modified (low-profile) Ilizarov fixation in the treatment of osteoporotic fractures of the distal femur. The system was composed of tensioned olive wires attached to four 5/8 rings (two proximal and two distal to the fracture line) connected to each other with three rods. The fixator was not extended to the proximal femur nor across the knee to the tibia, and no Schanz screws were used. Considering the high union and low complication rates, Cavusoglu et al. suggested the use of a low-profile Ilizarov fixator in the management of certain distal femoral fractures and nonunions that may be difficult to manage using other means of fixation [10].

The diversity of surgical options for the management of distal femoral fractures reflects the challenges inherent in these injuries. These fractures are frequently comminuted and intra-articular, and they often involve osteoporotic bone, which makes it difficult to reduce and hold them while maintaining joint function and overall limb alignment. Surgery has become the standard of care for displaced fractures and for patients who must obtain rapid return of knee function. The goal of surgical management is to promote early knee motion while restoring the articular surface, maintaining limb length and alignment, and preserving the soft tissue envelope with a durable fixation that allows functional recovery during bone healing. A variety of surgical exposures, techniques, and implants have been developed to meet these objectives, including intramedullary (IM) nailing, screw fixation, and periarticular locked plating, possibly augmented with bone fillers. Recognition of the indications and applications of the principles of modern implants and techniques is fundamental in achieving optimal outcomes [12, 13].

According to Hierholzer et al. [14] two major therapeutic principles can be employed for the treatment of distal femoral fractures: retrograde IM nailing or less invasive stabilization on system (LISS). Both operative stabilizing systems follow the principle of biological osteosynthesis. IM nailing protects the soft tissue envelope due to its minimally invasive approach and closed reduction techniques better than distal femoral locked plating. The main conclusion was that both retrograde IM nailing and angular stable plating are adequate treatment options for distal femur fractures. Locked plating can be used for all distal femur fractures including complex type C fractures, periprosthetic fractures, as well as osteoporotic fractures. IM nailing provides favorable stability and can be successfully implanted in bilateral or multisegmental fractures of the lower extremity as well as in extra-articular fractures. However, both systems require precise preoperative planning and advanced surgical experience to reduce the risk of revision surgery. Clinical outcome largely depends on surgical technique rather than on the choice of implant [14].

Nonunion of supracondylar femur fracture remains a challenging problem because of limited treatment options. The situation is more complex when it occurs in elderly patients with osteoporotic bones. Pao and Jiang [15] reported the treatment of three elderly patients with supracondylar femur fracture nonunion after open reduction and internal fixation with various plate-screw internal fixation systems. Two of these patients had traumatic fractures, and the third had a periprosthetic fracture after primary total knee arthroplasty (TKA). After revision surgeries using retrograde nailing techniques, all fractures united eventually. When combined with indirect reduction, these techniques provided superior biomechanical properties and reduced the need for soft tissue dissection.

Hailer and Hoffmann presented a case illustrating the successful use of the internal fixation LISS in an osteoporotic nonunion of the distal femur, where classic osteosynthesis has failed [16]. The LISS plate with its angular stability offered the possibility to achieve excellent purchase in the severely porotic and partially destroyed bone. In combination with the use of an autologous bone graft laterally and a strut cortical autograft medially, a mechanical support and an osteoinductive stimulus were provided, and the extremity could be saved by this procedure.

To date, there is no convincing technique for managing femoral supracondylar nonunions. When the nonunion is associated with severe osteoporosis, treatment becomes even more complicated. Wu [17] developed a modified retrograde locked nailing technique to treat this complex lesion. Twenty-four aseptic femoral supracondylar nonunions with severe osteopenia in 24 elderly patients (aged ≥65 years) were treated. A retrograde femoral locked nail was inserted in the dynamic mode. Next, the medial ½ to 2/3 marrow cavity in the nonunion site was filled with bone cement, and the lateral 1/3 to ½ marrow cavity received a cancellous bone graft with or without a bone graft substitute. A cylindrical brace was applied for 3 weeks postoperation. Early ambulation with a walker or wheelchair was encouraged. Twenty patients were followed up for an average period of 2.5 years, and 18 nonunions healed. The union rate was 90 % with an average union period of 5 months (range, 4–7 months). No deep infection or malunion was found. The two patients with persistent nonunions were advised to use a walker whenever necessary. The satisfactory rate for knee function improved from 0 % preoperatively to 80 % at the latest follow-up. The described technique may concomitantly provide sufficient stability and initiate osteogenic potential, thus facilitating bone union. This technique is simple with a low complication rate and thus should be considered as a useful alternative for treating these complex lesions [17].

16.3 Proximal Tibia Fractures

Complex intra-articular fractures of the proximal tibia are difficult to treat, especially in the elderly osteoporotic patient. Preexisting OA, cartilage damage during trauma, suboptimal reduction, and fixation due to poor bone stock and/or secondary displacement frequently lead to poor outcome [18]. After osteosynthesis, rehabilitation is paramount as patients have been non-weight bearing for long periods of time and secondary TKA can be challenging. For these reasons, Vermeire and Scheerlinck investigated the possibility to perform a TKA with or without adjuvant osteosynthesis as a primary treatment in elderly and/or osteoarthritic patients with complex tibial plateau fractures [18]. In a 7-year period, 12 patients (mean age, 73 years) with an AO-41 fracture types B1 (1), B3 (8), and C3 (3) were treated with a primary TKA within 3 weeks from their trauma. Most patients (7/12) were allowed early full weight bearing. One patient died due to an unrelated cause; the remaining 11 were reviewed at a mean follow-up period of 31 months. At final follow-up, the median knee score was 78 and the function score 58: 7/11 patients had an excellent result, while 1/11 had a fair and 3/11 a poor result. Fair and poor results were mostly related to preexisting poor general condition and/or concomitant disease. Most patients were satisfied, and only minor short- and long-term complications were noted. There was no need for revision surgery. This limited series of well-selected elderly and/or osteoarthritic patients with a complex tibial plateau fracture treated with primary TKA yielded encouraging results [18].

According to Veitch et al. [19], displaced tibial plateau fractures are traditionally treated with internal fixation using autologous bone grafting to provide structural support. In osteoporotic fractures, there can be insufficient autograft available for this. Fresh-frozen bone allograft is readily available in sufficient quantity to fill all voids, is relatively inexpensive, and avoids donor site morbidity. They described their technique and the early clinical and radiologic results of compaction morselized bone grafting (CMBG) for displaced tibial plateau fractures using fresh-frozen allograft. This technique had been performed on eight patients. One patient died of an unrelated cause 3 months after surgery, and one patient failed to attend follow-up clinic. Clinical and radiologic follow-up was performed on the remaining six patients at an average 15 months after surgery. One patient underwent a manipulation under anesthesia at 3 months for knee stiffness. One patient developed a painless valgus deformity and underwent a corrective osteotomy at 15 months. The height of the tibial plateau on radiographs has been maintained to an excellent grade (less than 2 mm depression) in all but one patient. The main conclusion was that CMBG using fresh-frozen allograft in depressed tibial plateau fractures provides structural support sufficient to maintain the height of the tibial plateau, is associated with few complications in complex patients with large bone loss, and has theoretical advantages of graft incorporation and remodeling [19].

Intra-articular fractures of the proximal tibia that extend to the meta-diaphyseal part of the bone represent a severe injury, especially if they occur in osteoporotic patients. Current treatment modalities include either internal fixation with traditional or modern plating techniques or external fixation with circular frames or hybrid systems. However, problems and complications related with these techniques are increasing with age, and future reconstructive operations, such as TKA, may be jeopardized. Garnavos et al. [20] performed a prospective pilot study about a novel type of osteosynthesis for complex intra-articular proximal tibial fractures without significant articular impaction. Within a period of 4.5 years, eight patients underwent fixation of such fractures with condylar compression bolts and IM nailing. The mean follow-up period was 1 year. There were no neurovascular complications, wound infections, delayed unions, or nonunions. All patients had their fractures healed without secondary displacement or malalignment. At the final follow-up, all patients had full extension of the knee joint, while the flexion ranged from 125° to 140°. The mean new Oxford Knee Score was calculated to be 44 points. The main conclusion was that the management of selected osteoporotic complex intra-articular fractures of the proximal tibia with compression bolts and IM nailing offers specific advantages and, in the present pilot study, provided promising results [20].

16.4 Other Peri-knee Fractures

Modified anterior tension wiring with K-wires and cannulated lag screws with anterior tension wiring are currently the fixation of choice for osteoporotic patellar fractures. Failure of fixation, migration of the wires, postoperative pain, and resulting revision surgery, however, are not uncommon. After preliminary biomechanical testing of a new fixed-angle plate system especially designed for fixation of patella fractures, Wild et al. [21] evaluated the surgical and anatomical feasibility of implanting such a plate device at the human patella. In six fresh unfixed female cadavers without history of previous fractures around the knee (average age 89 years), a bilateral fixed-angle plate fixation of the patella was carried out after previous placement of a transverse central osteotomy. Operative time, intraoperative problems, degree of retropatellar OA (following Outerbridge), quality of reduction, and existence of any intra-articular screw placement have been raised. In addition, lateral and anteroposterior radiographs of all specimens were made. Due to the high average age of 89 years, no patella showed an unimpaired retropatellar articular surface and all were severely osteoporotic, which made a secure fixation of the reduction forceps during surgery difficult. The operation time averaged 49 min. Although in postoperative X-rays the fracture gap between the fragments was still visible, the analysis of the retropatellar surface showed no residual articular step or dehiscence >0.5 mm. Also in a total of 24 inserted screws, not one intra-articular malposition was found. No intraoperative complications were noticed. The main conclusion was that osteosynthesis of a medial third patella fracture with a bilateral fixed-angle plate device is surgically and anatomically feasible without difficulties. Further studies have to depict whether the bilateral fixed-angle plate osteosynthesis of the patella displays advantages over the established operative procedures.

Two patients with Hoffa fracture of the knee, both suffering from poliomyelitis, were reported by Chang et al. [22]. Both had unicondylar coronal plane fracture of the medial femoral condyle. The patients were treated with open reduction and screw fixation. Due to poor screw purchase, reoperation was necessary in one patient. The results were satisfactory in both patients.

Conclusions

Operative fixation options of osteoporotic supracondylar fractures of the knee include open reduction and internal fixation, intramedullary nailing, and bridge plating or percutaneous submuscular plating techniques. As with any fracture, treatment choice must be individualized according to the nature of the injury, bone quality, and patient demand. Regardless of treatment method, goals include restoration of articular congruity, anatomical length, rotation, and axial alignment while establishing adequate fixation to initiate early and unrestricted range of motion. Displaced tibial plateau fractures must be treated with internal fixation using autologous bone grafting to provide structural support. In comminuted and osteoporotic fractures, there can be insufficient autograft available for this. Fresh-frozen bone allograft is readily available in sufficient quantity to fill all voids, is relatively inexpensive, and avoids donor site morbidity. Intra-articular fractures of the proximal tibia that extend to the meta-diaphyseal part of the bone represent a severe injury, especially if they occur in osteoporotic patients. Current treatment modalities include either internal fixation with traditional or modern plating techniques or external fixation with circular frames or hybrid systems. However, problems and complications related with these techniques are increasing with age, and future reconstructive operations, such as TKA, may be jeopardized. Further studies have to depict whether the new bilateral fixed-angle plate osteosynthesis of the patella displays advantages over the established operative procedures (modified anterior tension wiring with K-wires and cannulated lag screws with anterior tension wiring).

References

1. Kannus P, Niemi S, Palvanen M et al (2001) Continuously rising problem of osteoporotic knee fractures in elderly women: nationwide statistics in Finland in 1970–1999 and predictions until the year 2030. Bone 29:419–423
2. Adachi JD, Ioannidis G, Pickard L et al (2003) The association between osteoporotic fractures and health-related quality of life as measured by the Health Utilities Index in the Canadian Multicentre Osteoporosis Study (CaMos). Osteoporos Int 14:895–904
3. Arden NK, Griffiths GO, Hart DJ, Doyle DV, Spector TD (1996) The association between osteoarthritis and osteoporotic fracture: the Chingford Study. Br J Rheumatol 35:1299–1304
4. Liu F, Tao R, Cao Y et al (2009) The role of LISS (less invasive stabilisation system) in the treatment of peri-knee fractures. Injury 40:1187–1194
5. Horwitz DS, Kubiak EN (2010) Surgical treatment of osteoporotic fractures about the knee. Instr Course Lect 59:511–523
6. Struhl S, Szporn MN, Cobelli NJ, Sadler AH (1990) Cemented internal fixation for supracondylar femur fractures in osteoporotic patients. J Orthop Trauma 4:151–157
7. Kumar A, Jasani V, Butt MS (2000) Management of distal femoral fractures in elderly patients using retrograde titanium supracondylar nails. Injury 31:169–173
8. Ito K, Hungerbühler R, Wahl D, Grass R (2001) Improved intramedullary nail interlocking in osteoporotic bone. J Orthop Trauma 15:192–196
9. Ingman AM (2002) Retrograde intramedullary nailing of supracondylar femoral fractures: design and development of a new implant. Injury 33:707–712
10. Higgins TF (2007) Distal femoral fractures. J Knee Surg 20:56–66
11. Cavusoglu AT, Ozsoy MH, Dincel VE, Sakaogullari A, Basarir K, Ugurlu M (2009) The use of a low-profile Ilizarov external fixator in the treatment of complex fractures and non-unions of the distal femur. Acta Orthop Belg 75:209–218
12. Gwathmey FW Jr, Jones-Quaidoo SM, Kahler D, Hurwitz S, Cui Q (2010) Distal femoral fractures: current concepts. J Am Acad Orthop Surg 18:597–607
13. Nayak RM, Koichade MR, Umre AN, Ingle MV (2011) Minimally invasive plate osteosynthesis using a locking compression plate for distal femoral fractures. J Orthop Surg (Hong Kong) 19:185–190
14. Hierholzer C, von Rüden C, Pötzel T, Woltmann A, Bühren V (2011) Outcome analysis of retrograde nailing and less invasive stabilization system in distal femoral fractures: a retrospective analysis. Indian J Orthop 45:243–250
15. Pao JL, Jiang CC (2005) Retrograde intramedullary nailing for nonunions of supracondylar femur fracture of osteoporotic bones. J Formos Med Assoc 104:54–59
16. Hailer YD, Hoffmann R (2006) Management of a nonunion of the distal femur in osteoporotic bone with the internal fixation system LISS (less invasive stabilization system). Arch Orthop Trauma Surg 126:350–353
17. Wu CC (2011) Modified retrograde-locked nailing for aseptic femoral supracondylar nonunion with severe osteoporosisin elderly patients. J Trauma 71:E26–E30
18. Vermeire J, Scheerlinck T (2010) Early primary total knee replacement for complex proximal tibia fractures in elderly and osteoarthritic patients. Acta Orthop Belg 76:785–793
19. Veitch SW, Stroud RM, Toms AD (2010) Compaction bone grafting in tibial plateau fracture fixation. J Trauma 68:980–983
20. Garnavos C, Lasanianos NG (2011) The management of complex fractures of the proximal tibia with minimal intra-articular impaction in fragility patients using intramedullary nailing and compression bolts. Injury 42:1066–1072
21. Wild M, Thelen S, Jungbluth P et al (2011) Fixed-angle plates in patella fractures – a pilot cadaver study. Eur J Med Res 16:41–46
22. Chang JJ, Fan JC, Lam HY, Cheung KY, Chu VW, Fung KY (2010) Treatment of an osteoporotic Hoffa fracture. Knee Surg Sports Traumatol Arthrosc 18:784–786

Rehabilitation in Complex Fractures of the Limbs

17

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17.1 Introduction

Trauma, in general, and complex fractures, in particular, are often the cause of pain and disability. They affect a very heterogeneous population with regard to age, reducing quality of life as soon as the injury occurs, so they are of special interest for rehabilitation specialists. Complex bone injuries of the extremities are often found in patients subject to multiple trauma and can be associated with organ, vertebral and neurological injuries, burns and amputations.

The functional impact and degree of disability derived from different trauma depend on the fracture's characteristics: location, fragmentation, possibility of reduction, stability, etc. In most cases, the indicated therapy is surgery, and appropriate postsurgical rehabilitation is fundamental for ensuring the patient's greatest functional recovery.

Said postsurgical rehabilitation must always be prescribed individually, and, therefore, discussions on rehabilitation in complex fractures can be as broad as discussions on each type of fracture and surgical technique. All the different specific rehabilitation programmes available can therefore not be described in the space set aside for this chapter. Therefore, we will take a look at basic aspects and focus on common factors of complex fractures of the extremities, in relation to therapeutic objectives, rehabilitation techniques, degrees of disability and individual features. The goal of treatment is always to ensure that the patient recovers the greatest possible functional independence.

17.2 General Concepts

There is no single definition of a complex fracture. Several factors determine the possible complexity of fractures: intra-articular defects, comminution, associated soft tissue injuries, the coexistence of other musculoskeletal injuries (multiple fractures) or the association of high-energy trauma and at least two organ systems being affected (multiple trauma) [1]. This broad range of possible presentations, when referring to complex fractures, makes it very difficult to thoroughly discuss the rehabilitation aspect.

Rehabilitation should create a protected environment that facilitates tissue recovery while progressively improving function recovery in terms of pain control, improved articular and muscular

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balance and re-education regarding walking and everyday activities, all aimed at restoring the patient's previous degree of functionality.

For rehabilitation to be successful in a post-surgical context, communication between the surgeon and the physical medicine and rehabilitation specialist is essential. Details of the surgery, basically the type of injury, the exact procedure performed and any possible incidents occurring during the operation, are of the utmost importance when planning the best rehabilitation programme.

17.3 Clinical Assessment

When the rehabilitation medicine specialist visits a patient who has suffered some kind of trauma, he or she needs to know the type and severity of the injury or injuries, the treatment provided and the necessary duration of immobilisation. Also, in patients requiring later surgeries, it is important to consider the strategy to be applied in the future, in order to make the necessary adjustments to the rehabilitation.

The patient's symptoms, such as pain, inflammation and movement limitations, should all be assessed. The physical examination should be adapted to the patient's clinical and haemodynamic condition. Ideally, the assessment should consider static postural stability, external signs, pain, joint and muscle balance, neurovascular status, bimanual coordination and gait, if possible. Not only should the traumatic injury be assessed but also the patient's overall condition, which could be less than optimal for other reasons, including cardiorespiratory lesions, concomitant diseases, age, prior immobilisation, cognitive status, sequelae from previous injuries, medication, etc. [2].

Validated scales are useful for quantifying the patient's functional status, measuring the efficacy of the surgery and monitoring the patient's clinical and functional progress. There are currently multiple scales available, and we only highlight those that we believe are the most interesting for assessing patients with complex fractures. General scales that measure quality of life are SF-36 (Short Form-36), SF-12, Nottingham Health Profile and EuroQol. There are also regional scales that assess function, pain or satisfaction with the performed procedure. The DASH (Disabilities of the Arm, Shoulder and Hand) is available for overall assessment of the upper extremity. If we specifically want to assess an upper extremity joint, we can use the Constant-Murley scale for the shoulder, the PREE (Patient-Rated Elbow Evaluation) scale for the elbow or the Gartland-Werley scale for the wrist and hand. We can use the Hip and Knee Outcomes Questionnaire for overall assessment of the lower extremity. For a specific assessment of a lower extremity joint, we can use the Harris Hip Score for the hip, the KSS (Knee Society Score) for the knee and the FAAM (Foot and Ankle Ability Measure) for the ankle and foot [3].

17.4 Objectives of Rehabilitation

The basic goal of rehabilitation in patients with complex fractures of the extremities is to achieve the greatest functional recovery in the shortest possible time, respecting regimens that ensure bone consolidation and tissue repair [4]. An early start to rehabilitation is ideal, even when the segment is immobilised, without compromising the anatomical result of the fracture's treatment, as it does not necessarily involve the patient's complete immobilisation.

During the more acute phases, it is fundamental to maintain appropriate haemodynamic stability, relieve pain, follow postural recommendations and use therapeutic techniques that hold the limb in the best possible conditions with regard to alignment, joint, muscle, vascular and neurological status. It is also important for treatment to be designed to prevent complications such as retraction, adhesions or demineralisation.

In the long term, rehabilitation of a patient who has suffered one or more complex fractures of the extremities, usually treated by surgery, aims to break up adhered tissues; improve joint range of motion, muscle strength and proprioception; and, ultimately, restore the injured limb's function. In the case of fractures of the upper

Table 17.1 Description of the physical methods used in rehabilitation

Thermal therapy	It uses temperature changes in a region of the body
Electrotherapy	It uses different types of nonionising radiation
Ultrasound and shock wave therapy	Application of the effects of different mechanical waves
Sun therapy and thalassotherapy	Effect of different natural or modified media, such as sunshine and sea water
Kinesitherapy	Effect of physical exercise or movement

extremity, this involves improving manual abilities and skills as required for everyday activities. In the case of lower extremity injuries, it involves teaching patients to walk and climb stairs again.

There are different treatments available, such as oral medication, infiltration, orthoses, technical aids and the use of different physical methods. With regard to the latter, there is a large range of treatment techniques that can be classified according to the physical principle on which they are based, as shown in Table 17.1.

17.5 Rehabilitation Techniques

The most commonly used rehabilitation techniques in patients with complex fractures, which also have the best outcomes, are postural re-education, kinesitherapy (including early movement, muscle reinforcement, proprioceptive work and cardiovascular activity) and occupational therapy (including training in self-help activities). These should be prescribed according to the patient's clinical characteristics, the surgery performed and the patient's progress so they are always prescribed on an individual basis. Also, surgery on one area does not usually require the patient's complete immobilisation so physical therapy should be performed on unaffected areas.

On the other hand, other therapeutic techniques can also be very useful for achieving some therapeutic objectives. These include prevention of venous thrombosis (early movement, intermittent pneumatic compression or compression stockings) [5], pain control measures (analgesic medication, TENS), cryotherapy (local use of cold temperatures to reduce bleeding and pain), tissue release (massotherapy to reduce the risk of fibrosis), electrical stimulation of denervated muscles, hydrotherapy (provided that the surgical wounds have healed, this supports the body's weight while performing flexibilisation and muscle reinforcement exercises) [6], magnetic therapy and mechanical waves (ultrasound or shock waves).

17.6 Specific Treatments in Complex Fractures

17.6.1 Conservative Treatment

Despite the severity of complex fractures, due to the difficult surgical techniques involved or the patient's age or comorbidity, the surgeon may decide to apply conservative treatment, usually comprising immobilisation of the affected area or areas.

When the upper limb is affected, this obviously has an impact on everyday activities such as personal hygiene, dressing or eating. When it affects the lower limbs, weight-bearing is not usually permitted for some time to enable satisfactory consolidation (walking is therefore usually limited).

Rehabilitation should aim to maintain adequate trophism and mobility of non-immobilised areas while maintaining cardiovascular status with active exercises. In the immobilised area, when not contraindicated by lesions, postural treatment with elevation can be used to improve blood and lymphatic circulation, together with isometric exercises. With isometric contractions, muscle activity is generated without changing muscle length. It is a contraction that can safely be prescribed whenever joint mobilisation presents a risk. However, it can generate major stress on the muscle so should be used with caution with muscle or tendon injuries. When prescribing exercise, we must provide the patient with the most accurate information possible. The patient's resistance should be personalised for each contraction, as should the number of repetitions and sets and their progression.

Once immobilisation is no longer necessary and weight-bearing is allowed, the therapeutic programme advances with the aforementioned objectives and techniques [6].

17.6.2 Definitive Surgery

Despite the wide variety of options available for the surgical treatment of such fractures, they all have one thing in common; they attempt to safely restore anatomy and function in the shortest possible time. We therefore have to start with passive and active exercises whenever possible, with the patient walking as soon as he/she is authorised to do so by the surgeon.

There are four basic aspects to be considered when designing a rehabilitation programme for a patient who has undergone surgery for a complex fracture:

- Pain and inflammation. Their control is very important for ensuring compliance with the rehabilitation programme.
- Range of motion. We need to know whether there are limitations in any ranges of motion due to the characteristics of the surgery or associated injuries.
- Muscle strengthening. This should start as soon as possible to prevent amyotrophy and weakness.
- Weight-bearing load on limb. The idea is to determine the load that can be authorised for the limb and whether orthoses are required for support.

In this respect, we primarily consider the following surgical options:

Open reduction and internal fixation. These usually enable active movement with the injured limb. On lower limbs, loading is usually permitted with diaphyseal fractures, although a no-load period is usually required with intra-articular fractures. In type B acetabular fractures (affecting both columns, partially intra-articular), loading and passive movement are usually restricted in the early phases.

External fixator. Passive movements with no weight-bearing load are usually permitted. Extreme precautions are required to ensure asepsis, and the fixator should never be touched.

Arthroplasty. This is usually performed in complete acetabular fractures or complex tibial plateau fractures. They initially permit active movement and weight-bearing loading on the limb. For the upper limb, this is usually performed on multi-fragmented fractures or the proximal humerus and elbow. Assisted passive movements are usually allowed for a start, progressing to active movements after a few weeks.

Amputation. This is performed when the limb is not viable or when advisable in view of the patient's haemodynamic condition. The use of prostheses on the upper and lower limbs is very complex and does not fall within the scope of this chapter. We would merely like to highlight the fact that the purpose of a prosthesis can be functional or merely cosmetic and there are no clinical practice guidelines in this respect; the rehabilitation medicine specialist's expertise is therefore fundamental for prescribing the most appropriate prosthesis for each patient.

17.6.3 Two-Step Surgery

Definitive surgery often has to be delayed due to clinical or haemodynamic instability or local factors such as poor soft tissue control.

These aspects must be clear when determining a rehabilitation programme. When several surgeries are performed, one after the other, on the same patient, precautions and considerations vary enormously as the patient progresses. For example, a patient with a pelvic injury might initially require a pelvic binder and rest and subsequently undergo open surgery to enable active movement and weight-bearing load, as tolerated.

The most common predefinitive options are:

- Traction: This does not allow mobilisation or weight-bearing loads on the extremity.
- External fixator: This does not allow mobilisation or weight-bearing loads on the extremity. Active mobilisation with no load can be permitted in partially stable pelvic fractures.
- Pelvic binder (in completely or partially unstable pelvic fractures): This does not allow

mobilisation or weight-bearing loads on the extremity.

Once the definitive surgery is performed, and as mentioned earlier, the therapeutic objectives change.

17.6.4 Multiple-Trauma Patient

A multiple-trauma patient presents high-energy trauma with injuries to at least two organ systems and a score of more than 16 on the Injury Severity Score. As well as the initial injuries, these patients suffer a secondary process, systemic inflammatory response syndrome, which causes added organ damage, and they usually develop muscle weakness of multifactorial origin (nutritional disorders, pharmacological effects, neuropathic changes, physical inactivity and long-term bed rest) [7]. This combination of physiopathological circumstances determines the great complexity of the medical, surgical and rehabilitation management of these patients.

There is a traditional medical culture that recommends bed rest for critical patients, including those with multiple trauma. It is now believed, however, that bed rest is not only non-beneficial but can even be detrimental for the patient's recovery [8]. The negative effects of bed rest are described in Table 17.2 [9]. In this respect, there is growing evidence that early mobilisation of critical patients is well tolerated, is safe, improves the patient's clinical condition and also favours his or her prognosis of recovery [10, 11]. Multiple-trauma patients are often young, with a good previous baseline status, so early physical medicine could be especially indicated [12]. To safely restore functionality in these complex patients is a challenge faced by all professionals involved in their care. Definitive treatment is often postponed until a later date, according to damage control theory. A multidisciplinary approach can therefore provide better patient care.

The rehabilitation medicine specialist's function consists of making a thorough assessment of multiple-trauma patients considering their previous baseline status and using a functionality-oriented approach. Specific functional recovery targets must be established and an individual therapeutic programme adapted to the patient's needs, and current clinical condition must be designed.

Table 17.2 Negative consequences of bed rest

Thromboembolism
Collapsed lung
Insulin resistance
Impaired microvascular function
Systemic inflammatory response syndrome
Bed sores
Amyotrophy and deterioration in physical condition
Retraction of soft tissue with joint stiffness

Reproduced with permission from Brower [9]

Early physical therapy, especially mobilisation and assisted walking, is highly beneficial for multiple-trauma patients [13]. Resistance exercise increases muscle protein synthesis, which is reduced with bed rest [14]. Muscle immobilisation in the shortened position reduces the number of sarcomeres, while passive stretching reduces amyotrophy [15]. Early walking also appears to reduce bed rest, the duration of ICU admissions and total hospital stays without increasing the number of complications [16].

There are no specific studies providing a detailed assessment of the different injuries found in multiple-trauma patients and their limitations when establishing a rehabilitation programme. It is therefore essential to use clinical experience, logic based on physiopathology and a multidisciplinary approach. The known benefits of starting early physical therapy must be weighed against the possible risks.

In multiple-trauma patients, their fractures will require one of the three aforementioned options: conservative treatment, damage control surgery or definitive surgery. These treatments can also be applied alone or one after the other.

Other injuries to be considered when prescribing rehabilitation for multiple-trauma patients, with special consideration of mobilisation, are:

Chest trauma: Pulmonary and oesophageal injuries do not usually lead to restrictions. Monitoring may be required in cardiac lesions.

Head/face trauma: Facial and jaw injuries do not usually limit mobilisation. When the eyes are affected or neurosurgery is performed, it is best to avoid manoeuvres that increase intraocular and/or intracranial pressure. Precaution is recommended if there are sensory, and particularly visual, problems.

Visceral injuries: Injuries affecting hollow organs (stomach, intestine and bladder), the diaphragm and the pancreas do not usually limit mobilisation. When other solid organs are affected (liver, spleen and kidney), walking is usually limited depending on haemodynamic condition. Abdominal injuries usually require bed rest.

Spinal injury: If stable, they do not require immobilisation or limit mobility. When stability is questionable, they usually require appropriate orthoses depending on the injury's location. Unstable injuries require immediate or eventual surgery. They usually completely restrict axial mobility until they are surgically corrected and also later on depending on the technique used and the stability of the achieved synthesis.

17.6.5 Skin, Muscle and Tendon Repairs

It is fundamental to be familiar with how these injuries are managed in order to guide rehabilitation treatment. When there is an open wound, initial management consists of debriding and covering with a damp dressing. Occasionally, before coverage surgery, a negative-pressure wound therapy system is used to reduce inflammation while maintaining the wound's integrity [17]. While the wound is closing, the segment can be mobilised providing that tissue tension does not interfere with the healing process, so special precaution is required in joint areas.

If the wound is not very large, it is usually closed with a skin graft or deferred primary closure. If the wound is large, a free flap, a rotation flap or a combination of the two is usually necessary [18]. The presence of grafts or flaps usually requires a period of immobilisation to prevent avulsion, which could cause vascular compromise and ultimately graft failure. This period of immobilisation varies enormously depending on the type of flap, composition, blood supply, its complexity and location. Mobilisation exercises begin when this period is over.

If there are tendon injuries, the surgical decision is based on the type of injury, its location and the patient's local and overall clinical condition. When treatment is conservative, immobilisation is usually required to ensure tendon repair. If stitches are applied, subsequent management is considerably different. There is no consensus concerning the best rehabilitation programme. The current trend appears to consist of recommending a regimen of early active exercises, starting as soon as the first week after surgery. However, communication with the surgeon is fundamental for establishing an appropriate and safe rehabilitation programme [19].

17.6.6 Nerve and Vascular Repairs

Peripheral nerve injuries are usually acute and caused by fracture fragments. They occasionally arise due to the immobilisation device or the subsequent formation of a callus so should always be assessed during monitoring of fractures.

When there is an associated peripheral nerve injury in a fracture, paresis, amyotrophy, sensory disorders and even neuropathic pain will arise during its evolution. The prognosis will depend on the type of nerve injury in question. In this respect, Seddon's classification continues to be valid; it refers to neurotmesis (complete severance of the nerve), axonotmesis (axonal severance with preservation of the nerve sheath) and neurapraxia (functional alteration of the nerve with no anatomical solution of continuity). Complete surgical repair in the first two types of injury is also very important whenever possible. The usual surgical options are nerve decompression, repair or transfer. When there are surgical ligatures, a period of immobilisation is usually required to ensure the suture holds.

Rehabilitation of such injuries is controversial. There are animal models [20] that have shown improved nerve healing on combining electrical stimulation and active exercise. However, in humans, it has not been shown that electrical stimulation or active exercise improves nerve regeneration. It could possibly have an effect on the muscle innervated by the nerve in question, preserving its trophism.

In cases of neurotmesis when a satisfactory surgical repair is not possible, rehabilitation should be based on passive exercise to maintain range of joint motion and the prescription of a postural orthosis to prevent joint contractures and deformities, thus favouring the limb's functionality.

With regard to vascular lesions, when one has been repaired, there are no mobilisation constraints other than in infrapopliteal lesions, which will limit walking for 24–48 h. On many occasions, vascular shunting is preferred to a ligature in severe injuries. A vascular shunt is a synthetic tube that is inserted into the vessel and secured proximally and distally [21]. When this occurs, definitive vascular surgery must be delayed, usually requiring a period of immobilisation. In aortic lesions, the patient is constantly monitored so bed rest is usually recommended [22].

17.6.7 Defective Consolidation

Bone consolidation is a complicated repair process that creates new tissue between the edges of a fracture, called a callus. This process can take time or even fail, in which case we refer to it as pseudarthrosis.

The physical methods available to rehabilitation medicine specialists in these cases include:

Magnetic therapy: This is based on the use of low-frequency (10–100 Hz) magnetic fields for therapeutic purposes. It has no thermal effect, and, although it has some analgesic and anti-inflammatory effects, its most common effect consists of improving the scarring reaction and promoting bone formation [23].

Extracorporeal shock waves: These are high-intensity mechanical waves that promote tissue repair mechanisms by means of a little-known sound transduction effect. The use of this technique for the treatment of pseudarthrosis could be an alternative to be considered, particularly in view of its few undesirable effects [24].

Ultrasound: This consists of a series of waves produced by non-audible acoustic vibrations. In the pulsed mode, with nonthermal effect, its analgesic, anti-inflammatory and bone-forming effects are based solely on mechanical changes, promoting the rearrangement of collagen fibres [25].

Weight loading: Weight loading is beneficial for promoting osteoblastic activity and speeding up fracture repairs in loading areas [26]. However, in complex fractures, there are often partial or total loading constraints in which case support is not possible.

17.6.8 Heterotopic Ossification

This is the formation of ectopic bone in soft tissue. It is common in patients who have suffered severe injuries with a considerable inflammatory response, especially when associated with traumatic brain injury. It produces joint pain and limitation, so it is important to promptly identify and treat it [27].

The most effective treatment option is prevention in high-risk patients. It can be associated with pharmacological treatment with NSAIDs, bisphosphonates or the use of radiotherapy (which appears to be more effective but is more expensive and not always available).

The first line of therapy comprises assisted mobilisation, avoiding aggressive manoeuvres.

Heterotopic ossification has been treated with promising results using extracorporeal shock waves, improving both pain and mobility [28].

Surgical removal of ossification is considered when there is a major limitation to mobility, when a skin wound occurs or when it interferes in the use of a prosthesis [29]. Early rehabilitation is required after surgical removal of ossification in order to improve the functionality of the limb in question.

Conclusions

Complex fractures are a common source of pain and disability and are therefore of special interest to rehabilitation medicine. Bone stabilisation is a fundamental part of early interventions in patients with complex fractures. The characteristics of the fracture and concomitant injuries determine the possibility of either immediate or deferred surgery. We now know that long-term bed rest is not beneficial so, although one segment has to be immobilised, we can ensure activity using uninjured segments. The basic goal of rehabilitation in patients with complex fractures of the extremities is to achieve the greatest functional recovery in the shortest possible time, respecting regimens that ensure bone consolidation and tissue repair. In the case of the upper extremity, this involves improving abilities to carry out everyday activities. In the case of the lower extremity, it involves re-educating patients to walk again. Rehabilitation programmes must always be prescribed individually, after a thorough assessment of each patient's functional status, paying special attention to multiple trauma and soft tissue or neurovascular injuries. The most commonly used rehabilitation techniques in patients with complex fractures, which ensure the best outcomes, are postural treatment, kinesitherapy and occupational therapy. Other techniques, such as electrical stimulation, hydrotherapy, magnetic therapy, ultrasound or shock waves, can also be useful.

References

1. Simpson NS, Jupiter JB (1995) Complex fracture patterns of the upper extremity. Clin Orthop Relat Res 318:43–53
2. Peña Arrébola A (2004) Rehabilitación de las fracturas, luxaciones y esguinces. Secuelas: contractura, rigidez, anquilosis articular. Complicaciones: algodistrofia refleja postraumática. In: Miranda Mayordomo JL (ed) Rehabilitación Médica. Grupo Aula Médica, Madrid, pp 165–176
3. Castellet Feliu E, Vidal N, Conesa X (2010) Escalas de valoración en cirugía ortopédica y traumatología. Trauma Fund MAPFRE 21(Suppl 1):34–43
4. Fleming ME, Watson JT, Gaines RJ et al (2012) Evolution of orthopaedic reconstructive care. J Am Acad Orthop Surg 20:S74–S79
5. Castiella-Muruzábal S, López-Vázquez MA, No-Sánchez J et al (2007) Artroplastia de rodilla. Rehabilitación 41:290–308
6. Hustedt JW, Blizzard DJ, Baumgaertner MR et al (2012) Current advances in training orthopaedic patients to comply with partial weight-bearing instructions. Yale J Biol Med 85:119–125
7. Chambers MA, Moylan JS, Reid MB (2009) Physical inactivity and muscle weakness in the critically ill. Crit Care Med 37:S337–S346
8. Dock W (1944) The evil sequelae of complete bed rest. JAMA 125:1083–1085
9. Brower RG (2009) Consequences of bed rest. Crit Care Med 37:S422–S428
10. Kress JP (2009) Clinical trials of early mobilization of critically ill patients. Crit Care Med 37:S442–S447
11. Engels PT, Beckett AN, Rubenfeld GD et al (2013) Physical rehabilitation of the critically ill trauma patient in the ICU. Crit Care Med 41: 1790–1801
12. Holtslag HR, Post MW, van der Werken C et al (2007) Return to work after major trauma. Clin Rehabil 21:373–383
13. Needham DM (2008) Mobilizing patients in the intensive care unit: improving neuromuscular weakness and physical function. JAMA 300:1685–1690
14. Ferrando AA, Tipton KD, Bamman MM et al (1997) Resistance exercise maintains skeletal muscle protein synthesis during bed rest. J Appl Physiol 82: 807–810
15. Griffiths RD, Palmer TE, Helliwell T et al (1995) Effect of passive stretching on the wasting of muscle in the critically ill. Nutrition 11:428–432
16. Morris PE, Goad A, Thompson C et al (2008) Early intensive care unit mobility therapy in the treatment of acute respiratory failure. Crit Care Med 36: 2238–2243
17. Dedmond BT, Kortesis B, Punger K et al (2007) The use of negative-pressure wound therapy (NPWT) in the temporary treatment of soft-tissue injuries associated with high-energy open tibial shaft fractures. J Orthop Trauma 21:11–17
18. Pollak AN, Ficke JR (2008) Extremity war injuries: challenges in definitive reconstruction. J Am Acad Orthop Surg 16:628–634
19. Hammond K, Starr H, Katz D, Seiler J (2012) Effect of aftercare regimen with extensor tendon repair: a systematic review of the literature. J Surg Orthop Adv 21:246–252
20. Asensio-Pinilla E, Udina E, Jaramillo J et al (2009) Electrical stimulation combined with exercise increase axonal regeneration after peripheral nerve injury. Exp Neurol 219:258–265
21. Subramanian A, Vercruysse G, Dente C et al (2008) A decade's experience with temporary intravascular shunts at a civilian level I trauma center. J Trauma 65:316–324

22. Cook CC, Gleason TG (2009) Great vessel and cardiac trauma. Surg Clin North Am 89:797–820
23. Vavken P, Arrich F, Schuhfried O et al (2009) Effectiveness of pulsed electromagnetic field therapy in the management of osteoarthritis of the knee: a meta-analysis of randomized controlled trials. J Rehabil Med 41:406–411
24. Rodriguez de Oya R, Sánchez Bénitez deSoto J, García Munilla M (2001) Tratamiento de las pseudoartrosis y retardos de consolidación mediante ondas de choque extracorpóreas. Rev Orthop Traumatol 6:466–471
25. Rioja Toro J (2007) Ultrasonidos. In: Rioja Toro J (ed) Manual de Electroterapia. Tipografía Tavirense Lda, Tavira, pp 453–510
26. Meadows TH, Bronk JT, Chao EYS et al (1990) Effect of weight-bearing on healing of cortical defects in the canine tibia. J Bone Joint Surg Am 72:1074–1080
27. Potter BK, Forsberg JA, Davis TA et al (2010) Heterotopic ossification following combat-related trauma. J Bone Joint Surg Am 92(2):S74–S89
28. Brissot R, Lassalle A, Vincendeau S et al (2005) Treatment of heterotopic ossification by extracorporeal shock wave: 26 patients. Ann Readapt Med Phys 48:581–589
29. Potter BK, Burns TC, Lacap AP et al (2007) Heterotopic ossification following traumatic and combat-related amputations. Prevalence, risk factors, and preliminary results of excision. J Bone Joint Surg Am 89:476–486

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