European Manual of Medicine

Hans-Jörg Oestern · Otmar Trentz
Selman Uranues *Editors*

Bone and Joint Injuries

Trauma Surgery III

W. Arnold · U. Ganzer *Series Editors*

U.E.M.S.

Springer

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Foreword

The European Manual of Medicine series was founded on the idea of offering resident as well as specialized clinicians the latest and most up-to-date information on diagnosis and treatment in Europe. In contrast to existing textbooks, the European Manual of Medicine series aims to find a consensus on the demands of modern European medicine based on the "logbooks" recommended by the Union of European Medical Societies (UEMS). Therefore, for each discipline, those diagnostic and therapeutic principles that are generally considered best practice are presented as "recommended European standards."

To fulfill these demands, we – together with Springer – recruit editors who are well established and recognized in their specialties. For each volume, at least three editors from different European countries are invited to contribute the high clinical and scientific standards of their discipline to their book.

The volume's editors were asked to follow, wherever possible, a standardized structure for each chapter so as to provide readers quick and easy access to the material. High-quality illustrations and figures serve to provide additional useful information. Detailed references allow readers to further investigate areas of individual interest.

The series editors wish to express their sincere gratitude to Springer-Verlag, especially to Gabriele Schroeder and Sandra Lesny for their support and assistance in the realization of this project from the early stages.

The fifth volume of our European Manual of Medicine series is dedicated to trauma surgery and is published in three parts. The third part, presented here, focuses on bone and joint injuries. The first part deals with head, thoracic, abdominal, and vascular injuries, and the second part reports on general trauma care and related aspects.

One of the primary aims of this volume is to provide trainees with a comprehensive yet condensed guide to the core knowledge required in this broad surgical field and to give them the ability to work in their specialty throughout the European Union.

The volume editors, Prof. Hans-Jörg Oestern (Celle, Germany), Prof. Otmar Trentz (Zurich, Switzerland), and Prof. Selman Uranues (Graz, Austria), who are leading European experts in trauma surgery, recruited contributors from different European countries to compile a textbook that fulfills our original concept of the European Manual of Medicine series.

Munich, Germany — Wolfgang Arnold
Düsseldorf, Germany — Uwe Ganzer

Preface

Despite a decrease in motor vehicle injuries in most parts of Europe, there has been a dramatic increase globally in skeletal trauma. Sports injuries and geriatric trauma are also on the rise, and musculoskeletal injuries are the most common reason, after blunt trauma, for surgery.

Successful management of skeletal injuries requires an understanding of the underlying pathophysiology, diagnostic procedures, and treatment options. The aim of this third volume in the European Manual of Medicine Trauma Surgery series is to present a concise overview of what is currently considered to be good clinical practice for the treatment of musculoskeletal injuries.

General and trauma surgeons who want to refresh their knowledge or to prepare for their national boards or the European Board of Surgery Qualification (EBSQ) trauma exam will find this volume invaluable. The contributing authors are highly experienced trauma surgeons or specialists in their fields, with a strong commitment to trauma care.

We express our sincere gratitude to all the authors who contributed to this volume for sharing their expertise. Special appreciation also is due to Springer Publishing and, in particular, to Gabriele Schroeder, for putting this book in the works, and to Martina Himberger, for publishing it. Finally, we are very much indebted to Sandra Lesny for her support of both the editors and the authors.

Celle, Germany — Hans-Jörg Oestern
Zurich, Switzerland — Otmar Trentz
Graz, Austria — Selman Uranus

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Rotator Cuff Tears

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Martin Jaeger, Kaywan Izadpanah,
and Norbert P. Südkamp

1.1 Introduction

In 1834, G.A. Smith was the first to describe tears of the shoulder joint capsule and the supraspinatus tendon [1]. One hundred years later, in 1934, Codmann was convinced that these injuries predominantly occur during a trauma to the shoulder girdle [2]. Later, in 1939, Meyer and Burman hypothesized that all rotator cuff tears were the result of overuse or abrasion. In the ensuing years, our knowledge about etiology, diagnostics, and therapy has increased continuously. Treatment options include the full spectrum of nonoperative therapy and open, mini-open, and arthroscopic procedures. The latter seems to be today's gold standard. In massive cuff tears, tendon transfers might be considered. In cases of cuff tear, arthropathy shoulder replacement using reversed shoulder arthroplasty shows promising results.

1.2 Epidemiology

Rotator cuff tears are common injuries and are frequently seen by both general physicians and specialized shoulder surgeons. With increasing age, the prevalence of degenerative rotator cuff tears rises [3]. However, the true incidence of full-thickness and partial-thickness tears of the rotator cuff remains unknown. In cadaver observations the percentage of rotator cuff tears ranges from 17 to 19 %. Full-thickness tears were seen in people under 60 years in 6 % and in people over 60 years in 30 % [4, 5]. Yamamoto estimates the prevalence of rotator cuff tears in the general population by physical and ultrasonographic examinations. Of 1,366 shoulders, 20.7 % had full-thickness rotator cuff tears. Logistic regression analysis revealed a history of trauma, dominant arm, and age to be risk factors for a rotator cuff tear [6]. The prevalence of rotator cuff tears was 6.7 % in the age range from 40 to 49 years, 12.8 % in the range from 50 to 59 years, 25.6 % in the range from 60 to 69 years, 45.8 % in the range from 70 to 79 years, and 50 % in people older than 80 years.

1.3 Etiology

Multiple factors contribute to the development of a rotator cuff tear. These factors can be divided into two major categories: intrinsic factors and extrinsic factors [7, 8]. Age, vascularization, and tendon metabolism are considered intrinsic factors. Extrinsic factors are subacromial impingement, shoulder instability (typically anterior), blunt trauma, and repetitive micro-trauma.

1.4 Classifications

Several classification systems have been proposed for describing rotator cuff tears. This chapter outlines those relevant for preoperative planning and decision-making.

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Table 1.1 Classification of partial-thickness tears according to Ellman [9]

Partial-thickness tear (P): classification according to Ellman	
Grade	**Size**
I	<3 mm deep
II	3–6 mm deep
III	>6 mm deep
Localization	
A	Articular surface
B	Bursal surface
C	Interstitial

Table 1.2 Classification of partial-thickness tears according to Snyder [10]

Partial-thickness tears: classification according to Snyder	
Type	**Location of the tear**
A	Articular surface
B	Bursal surface
Type	**Severity of the tear**
0	Normal cuff, with smooth coverings of synovia and bursa
I	Minimal, superficial bursal or synovia irritation or slight capsular in a small localized area; usually <1 cm
II	Actually fraying and failure of some rotator cuff fibers in addition to synovial, bursal or capsular injury, usually <2 cm
III	More severe rotator cuff injury, including fraying and fragmentation of tendon fibers, often involving the whole surface of a cuff tendon (most often the supraspinatus); usually <3 cm
IV	Very severe partial rotator cuff tear that usually contains, in addition to fraying and fragmentation of tendon tissue, a sizable flap tear and often encompasses more than a single tendon

Table 1.3 Classification of full-thickness tears according to Ellman [9]

Full-thickness tear (F): classification according to Ellman		
Grade	**Size**	**Description**
I	<2 cm	Small
II	2–4 cm	Large
III	>4 cm	Massive
IV		Cuff arthropathy
Localization:		
A	Supraspinatus	
B	Infraspinatus	
C	Teres minor	
D	Subscapularis	

The tear size is estimated in the sagittal plane

Table 1.4 Classification of full-thickness tears according to Bateman [11]

Full-thickness tear: classification according to Bateman		
Grade	Size	Description
I	<1 cm	Small
II	1–3 cm	Medium
III	3–5 cm	Large
IV	>5 cm	Massive

The tear size is estimated in the sagittal plane

Table 1.5 Classification of full-thickness tears regarding the amount of tendon retraction according to Patte [12]

Full-thickness tear: classification according to Patte	
Grade	Description
I	Tendon between greater tuberosity and apex humeri
II	Tendon between apex humeri and glenoid
III	Tendon medial to glenoid

The tear size is estimated in the frontal plane

Rotator cuff tears can be distinguished in the following ways:

- Tendons affected
- Tear localization
- Tear size
- Retraction of the tendons
- Degeneration of the muscles

For partial-thickness tears, the classifications according to Ellman and to Snyder are commonly used. A special entity is the PASTA lesion (*p*artial *a*rticular *s*upraspinatus *t*endon *a*vulsion), which is an articular sided tear involving the supraspinatus footprint. This lesion can be defined as a type A-3 and A-4 lesion according to Snyder (Tables 1.1 and 1.2).

Most classifications of full-thickness tears involve the superior and posterior rotator cuff. They comprise the involved tendons and their tear size in the sagittal and frontal plane. The classifications according to Ellman, Bateman, and Patte are commonly used (Tables 1.3, 1.4, and 1.5).

Evaluation of muscle atrophy and fatty degeneration is important. This information provides valuable prognostic factors in addition to the tear size and retraction. Thomazaeu suggests that the ratio (R) of the supraspinatus muscle belly surface (S1) and the supraspinatus fossa surface (S2) is a good tool for estimating the degree of supraspinatus muscle atrophy [13]. Alternatively, according to Zanetti [14], the tangent sign is a quick, commonly used diagnostic procedure (Tables 1.6 and 1.7).

Subscapularis tendon tears can also be classified according to Fox and Romeo (Table 1.8).

Table 1.6 Classification of supraspinatus atrophy according to Thomazeau [13]

Supraspinatus atrophy: classification according to Thomazeau		
Grade	Ratio muscle/fossa supraspinata	Description
I	1.00–0.60	Normal or mild atrophy
II	0.60–0.40	Moderate atrophy
III	<0.40	Severe atrophy

Table 1.7 Classification of supraspinatus atrophy according to Zanetti [14]

Supraspinatus atrophy in MRI: classification according to Zanetti	
Positive tangent sign	A line ("tangent") is drawn through the superior borders of the scapular spine and the superior margin of the coracoid. Supraspinatus muscle lies underneath the tangent.
Negative tangent sign	A line ("tangent") is drawn through the superior borders of the scapular spine and the superior margin of the coracoid. Supraspinatus muscle lies above the tangent.

Table 1.8 Classification of subscapularis tears according to Fox and Romeo [15]

Tears of the subscapularis: classification according to Fox and Romeo	
Type	Description
I	Partial thickness tear
II	Complete tear of the upper 25 % of the tendon
III	Complete tear of the upper 50 % of the tendon
IV	Complete rupture of the tendon

1.5 Diagnostics

1.5.1 History

The typical history contains pain at night and painful elevation of the arm above the horizontal plane. Additionally, a loss of power may be observed. In advanced or acute cases, the patient is unable to elevate the arm at all; a pseudo-paralysis occurs. Many patients report a recent moderate trauma, however, most of cuff tears derive from a degenerative disease.

1.5.2 Clinical Examination

The clinical examination begins with the inspection of the complete shoulder girdle. Atrophies of the supraspinatus and infraspinatus muscles can be easily detected. Palpation of the anatomic landmarks is helpful to elicit pain spots. The active and passive range of motion should be documented according to the neutral zero method and functionally as well. Signs of capsular stiffness are crucial. Functional isometric testing of each rotator muscle is helpful but should be considered with care inasmuch as the powerful deltoid muscle might distort the involvement of the rotator cuff muscles. In these cases, the lag signs according to Hertel are valuable tests [16]. Additionally, impingement tests, according to Neer, Hawkins, and Kennedy, may underline the diagnosis. Specific tests for detecting pathologies of the long head of the biceps are also useful because they are seen frequently in association with rotator cuff tears and may influence later surgical therapy.

Finally, it is important to evaluate the cervical spine as well, inasmuch as many pain syndromes can derive from this area.

1.5.3 Plain X-Rays

Conventional X-rays should be carried out in all symptomatic patients. Without being able to view the rotator cuff tear itself, X-rays provide much crucial information. They can display differential diagnosis (e.g., calcifying tendinitis, severe acromioclavicular and glenohumeral joint arthritis). Moreover, they demonstrate the centering of the humeral head. An upward migration of the humeral head is a valuable diagnostic and prognostic factor in terms of rotator cuff tears. The acromiohumeral distance (AHD) is defined as the distance between the acromion and the top of the humeral head. If the AHD is smaller than 1 cm, the presence of a rotator cuff tear is indicated. An AHD greater than 7 mm implies a good prognosis for cuff repair [17]. AHD less than 5 mm indicates a poor prognosis. A cuff repair should be considered with care (Fig. 1.1).

1.5.4 Ultrasound

Ultrasound is a noninvasive and easy accessible method for investigation of the rotator cuff. In a recent meta-analysis, ultrasonography provided good sensitivity and specificity for the assessment of partial thickness rotator cuff tears (sensitivity: 0.84; specificity: 0.89). Even higher rates could be achieved in detection of full-thickness rotator cuff tears (sensitivity: 0.96; specificity: 0.93) [18]. A limitation of the method is that the detection of fatty muscle atrophy or tendon retraction underneath the acromion is impaired by technical limitations.

Fig. 1.1 Plain ap-view X-ray demonstrating an upward-migrated humeral head. The acromio-humeral distance is significantly reduced (4 mm)

1.5.5 Magnetic Resonance Imaging (MRI)

As with other joints, MRI has become a standard examination tool for investigation of the injured shoulder. In a recent meta-analysis of 44 studies with 2,710 patients, the pooled sensitivity and specificity values for the detection of partial-thickness rotator cuff tears were 0.80 (95 % confidence interval (CI): 0.79–0.84) and 0.95 (95 % CI: 0.94–0.97), respectively. The sensitivity and specificity values for the detection of full-thickness tears were 0.91 (95 % CI: 0.86–0.94) and 0.97 (95 % CI: 0.96–0.98), respectively [19]. In addition to the detection of the rotator cuff tear itself, it provides additional information such as tear size, morphology, retraction, muscle atrophy and fatty degeneration, tendon thickness, and quality [14] (Fig. 1.2).

1.6 Treatment

1.6.1 Nonoperative Treatment

1.6.1.1 Indications

- All forms of asymptomatic chronic rotator cuff tears
- All chronic rotator cuff tears, symptomatic <6 weeks

Fig. 1.2 Parasagittal sequence of MRI demonstrating a marked fatty degeneration of the supraspinatus muscle

1.6.1.2 Treatment

Nonoperative treatment of rotator cuff tears should include anti-inflammatory medication together with subacromial injection of local anesthetics and steroids no more than twice. This treatment should be supported by physical therapy. Physical therapy should aim for maintenance or restoration of free active and passive range of motion and strengthening of the shoulder girdle.

1.6.1.3 Results

Only a few studies have reported on the outcome of nonoperative treatment of rotator cuff tears. Additionally, most of these suffer a selection bias, as the study population was asymptomatic at the time of decision-making or undesirable for operative treatment. However, Bokor et al. reported on 53 patients treated nonoperatively with rotator cuff tears [20]. After 7 years, 74 % of patients had minor or no pain and 86 % rated their result as satisfactory. Two-thirds of the patients complaining of pain less than 3 months stayed asymptomatic until follow-up. Only 56 % of patients with symptoms for longer than 6 months remained asymptomatic. Patients with moderate symptoms can be managed nonoperatively over several years without significant progression of degenerative structural joint. But there is a risk of progression from a reparable to an irreparable tear within 4 years [21].

1.6.2 Operative Treatment

1.6.2.1 General Considerations

Christian Gerber once stated that the ideal tendon repair should have high initial fixation strength, allow minimal gap formation and maintain mechanical stability until solid healing has occurred [22]. Today, several fixation techniques meet these requirements. However, depending on the shape and size of the cuff tear or stage of tendon degeneration, tears reoccur in 11–94 % [3].

Fortunately, even after a re-rupture, the majority of patients experience significant increase of the shoulder scores, predominantly as a result of a reduction in pain.

Several studies demonstrate that clinical outcome and number of re-ruptures are comparable after arthroscopic or mini-open procedures for reconstruction of supraspinatus and subscapularis tears [23–25]. Therefore, the choice of the operative procedure should depend on the surgeon's skills. Further, there is no evidence for superiority of performing subacromial decompression at the time of rotator cuff reconstruction [26]. An evolution of fixation techniques can be seen in arthroscopic cuff repair. Single-row repair was followed by the development of double-row repair and double-row suture bridge repair techniques. In biomechanical testing, the primary stability of the double-row suture bridge technique seems to be superior in comparison to single-row fixation. They provide a higher load to failure, self-reinforcing characteristics (stronger under load), and better resistance to shear and rotational forces. In clinical studies, the double-row suture bridge repair tends to have higher outcome in shoulder scores and lower re-tear rates compared with single-row reconstruction in small and moderate tears [27–29]. However, in massive rotator-cuff tears, double-row fixation of the tendon provides significantly superior clinical and radiologic outcome [30].

1.6.2.2 Indication and Timing

Operative rotator-cuff reconstruction should be carried out after unsuccessful conservative treatment of 6–12 weeks or longer. Conservative treatment should not exceed 1 year, however, because significantly worse functional outcome can be expected [31]. This is probably because of the fatty degeneration of the muscles. Fatty muscle atrophy is hypothesized to begin after only a few weeks. Therefore, in young patients with traumatic rotator cuff tears early reconstruction should be the goal.

However, recent studies have not found fatty degeneration in the supraspinatus or subscapularis muscle within the first 12 weeks after trauma [32, 33]. In patients with chronic rotator cuff tears, operative treatment can be scheduled without hurry.

1.6.2.3 Patient Positioning

For arthroscopic treatment and open surgery of rotator cuff tears, two positions are commonly in use, depending on the procedure performed: the beach-chair position and the lateral decubitus position.

The beach-chair position can be used in almost all cases. It is used for the arthroscopic and open surgery of the rotator cuff. The lateral decubitus position is only used for arthroscopic treatment of the rotator cuff (Fig. 1.3).

1.6.3 Full-Thickness Tears of the (Postero-) Superior Rotator Cuff

1.6.3.1 Indications

- Traumatic rotator cuff tears
- Persistent shoulder impairment of longer than 3 months after physiotherapy

1.6.3.2 Contraindications

- Stiff shoulder/frozen shoulder
- AHD <5 mm
- Cuff tear arthropathy

1.6.3.3 Positioning

- Beach chair (arthroscopic, mini-open, and open repair)
- Lateral decubitus position (arthroscopic repair)

1.6.4 Arthroscopic Cuff Repair

1.6.4.1 Common Portals Used in Arthroscopic Cuff Repair

- Posterior portal
- Posterolateral portal
- Anterolateral portal
- Additional portals for anchor placement and/or suture management (Fig. 1.4)

1.6.4.2 Stepwise Technique

- Positioning in lateral or beach chair position
- Marking of anatomic landmarks and portals
- Placement of a posterior portal
- Standard glenohumeral inspection

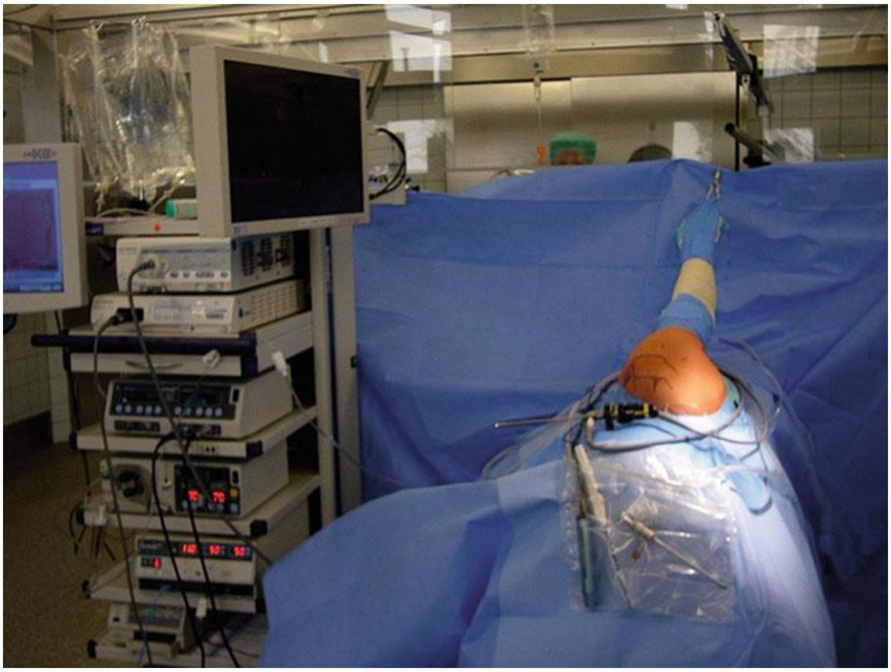

Fig. 1.3 Lateral decubitus position

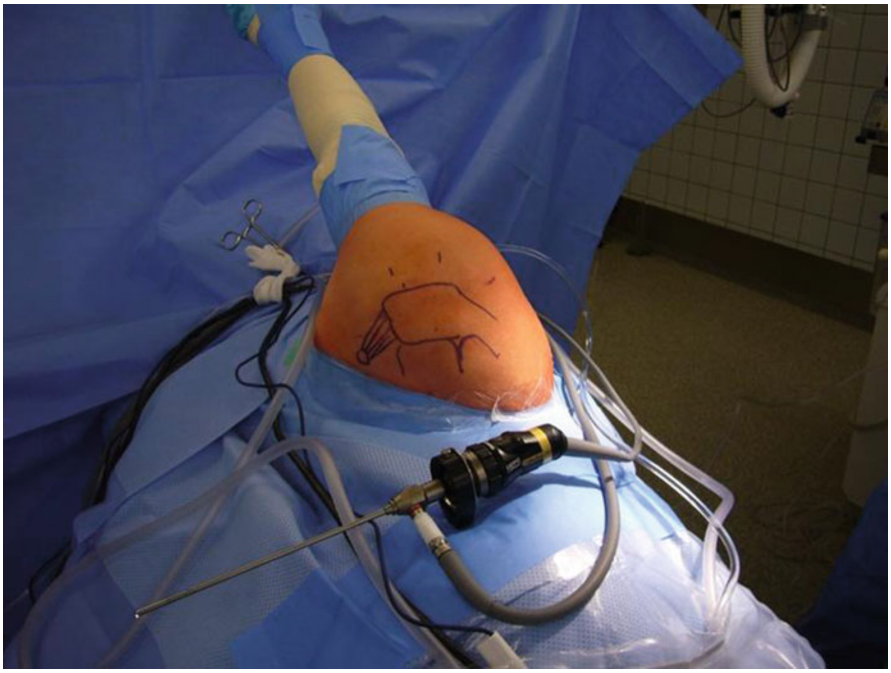

Fig. 1.4 Preoperative drawing of anatomical landmarks and portal placement

- In cases of pathologies and/or involvement of the long head of the biceps, arthroscopic tenotomy, and/or later tenodesis
- Redirection of the arthroscope into the subacromial space
- Subacromial bursectomy
- Evaluation of the subacromial space, the tear, the acromion, and the AC joint
- Performing an anterior-inferior acromioplasty
- Thorough rotator cuff release
- Identifying mobility of the cuff
- Debridement of the footprint using a burr

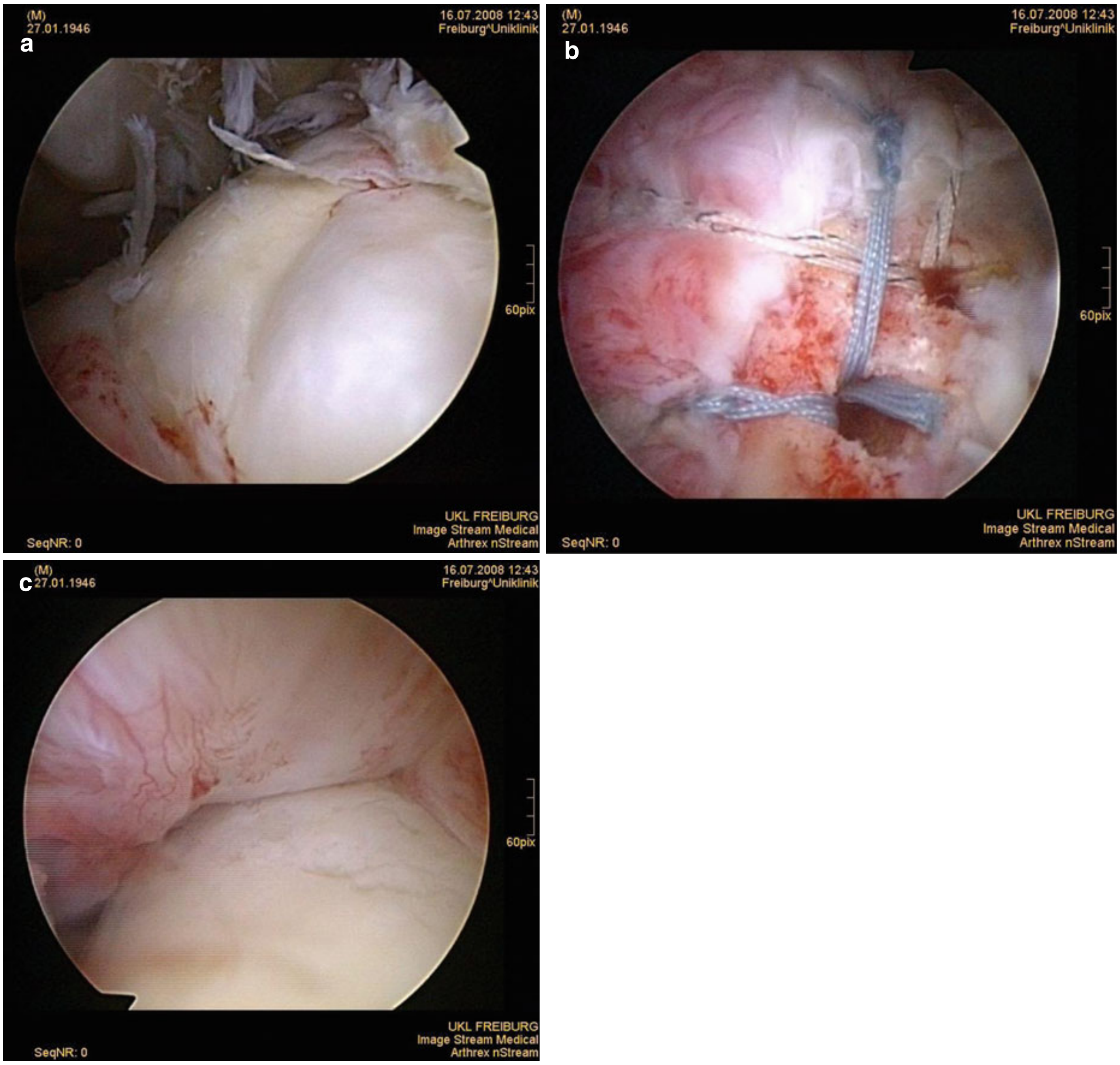

Fig. 1.5 (**a**–**c**) Arthroscopic cuff repair of a full-thickness supraspinatus tear. (**a**) Posterior view of the crescent-type tear. (**b**) Final control of double-row suture bridge repair. Subacromial view. (**c**) Final control. Intraarticular view

- Placement of a posterolateral optic portal//switching of the scope
- Switching the scope into the posterolateral portal
- Cuff repair using single-row or double-row suture bridge technique. Depending of the tear morphology, the following techniques are used:

Crescent type:	Lateral traction
L-shaped type:	Side-to-side closure, lateral fixation
U-shaped type:	Side-to-side closure, lateral fixation
Massive tear:	Side-to-side closure, lateral fixation (Figs. 1.5 and 1.6)

1.6.5 Mini-Open Repair

Mini-open repair begins with diagnostic arthroscopy of the shoulder joint followed by subacromial decompression (see above).

1.6.5.1 Stepwise Technique

- Anterolateral deltoid split in the line of fibers
- Thorough rotator cuff release
- Placement of stay sutures in the cuff for later manipulation

- Debridement of the footprint
- Creation of a trough in cases of foreseen transosseous fixation
- Reconstruction of the cuff tear with either single-row, double-row suture bridge, or transosseous techniques

1.6.5.2 Rehabilitation

A distinct postoperative rehabilitation protocol is crucial for a successful clinical outcome. Typically, the affected arm is placed on an abduction cushion for 6 weeks immediately after surgery. Continued passive motion exercises in this period can be performed but are not mandatory [34]. The rehabilitation program should be adapted to the fixated tendon. Recently, a prospective, randomized study demonstrated that aggressive rehabilitation has significantly higher rates of re-ruptures compared with a more moderate rehabilitation program within the first 6–8 weeks [35]. In the latter, the shoulder was predominantly fixed in a brace. Only guided movement supported by a well-trained physiotherapist was allowed (Table 1.9).

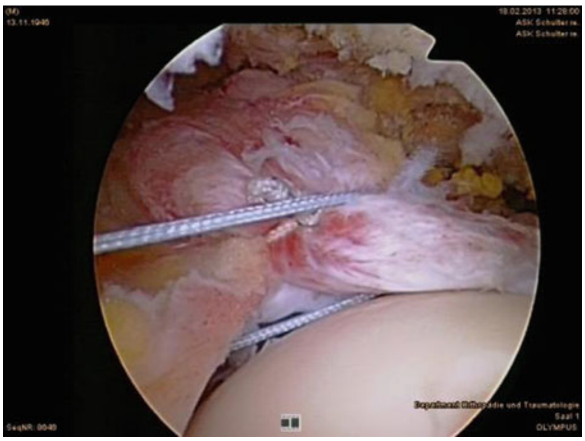

Fig. 1.6 Arthroscopic cuff repair of a U-shaped tear. Closure using side-to-side sutures and lateral fixation

1.6.5.3 Results

Mini-open and arthroscopic cuff repairs are a reliable treatment option. In a recent meta-analysis performed by DeHaan et al., a significant improvement was seen after a follow-up of 2 years [27]. The Constant-Murley score at the latest follow-up increased by 30 points after arthroscopic single- or double-row cuff repair, respectively. Complete re-tear rates were seen in 19 % of single-row and 14 % of double-row repair. Including partial tears, the re-tear rates were 43 % after the single row and 27 % after double-row repair. These are comparable results to mini-open surgery [24, 36]. Re-tearing is significantly influenced by patient's age, size, and extent of the tear, fatty degeneration of the rotator cuff muscles, and bone mineral density [37].

1.6.6 Full Thickness Tears of the Subscapularis Tendon

1.6.6.1 Indication

- All tears of the subscapularis tendon

Table 1.9 Proposal for a postoperative rehabilitation program after cuff repair

	1 p.o. day, week 1–3	Week 4–6	After 6 weeks	After 8 weeks
Brace	15° Shoulder abduction brace		None	None
Physiotherapy/CPM	Straining of the shoulder muscles Oscillation according to Maitland (Detonization of the capsule) Glenohumeral centering			
Range of motion	No active glenohumeral motion	Active moderate Flexion/Extension Slight internal and external rotation	Free No limitations for abduction and adduction	Free Strengthening of abduction and adduction
Training	Training of the forearm Training of the contralateral arm		Abduction 90° Adduction 90° External rotation up to 0° Internal rotation up to 0°	Training of coordination and 3D motion Increasing of power Isokinetic training of the internal and external rotation

Table 1.10 Proposal for a postoperative rehabilitation program after subscapularis repair

	1–2 p.o. day,	After 3 p.o. day, week 1–3	After 3 weeks	After 6 weeks
Brace	Sling/Gilchrist	Daytime: Omomed® Nighttime: Sling/Armfix®	None	
Physiotherapy/CPM	Assisted abduction 90° Preservation of scapular motion Glenohumeral stabilization Isometric Contraction		Free range of motion Straining of the subscapularis muscle	Active and passive motion against force
Range of motion	Abduction Extension passively up to 90° External rotation up to 0° No internal rotation against resistance		Motion in pain free range	Free

1.6.6.2 Contra-indication

- Stiff shoulder/frozen shoulder
- Chronic tears with fatty degeneration and marked narrowing of the subcoracoideal space

1.6.6.3 Positioning

- Beach chair (arthroscopic, mini open and open repair)
- Lateral decubitus position (arthroscopic repair)

1.6.7 Arthroscopic Repair

1.6.7.1 Common Portals Used in Arthroscopic Cuff Repair

- Posterior portal
- Anterolateral portal
- Anterolateral portals
- Additional portals for anchor placement and/or suture management

1.6.7.2 Stepwise Technique

- Beach chair position
- Marking of anatomic landmarks and portals
- Placement of a posterior portal
- Diagnostic glenohumeral evaluation
- Identifying intraarticular pathology
- Tenotomy/Tenodesis of the long head of the biceps
- Switch of the optic into an anterolateral portal
- Placement of additional anterior portals
- Bursectomy
- Thorough rotator cuff release
- Preparation of the bony footprint at the lesser tuberosity
- Reconstruction of the cuff tear with either single-row or double-row suture bridge technique

1.6.8 Open Repair

- Beach chair position
- Anterior deltopectoral approach
- Incision of the clavipectoral fascia
- Bursectomy
- Identification of the supraspinatus and the subscapularis tendon and placement of stay sutures
- Tenotomy of the biceps tendon
- Thorough release of the subscapularis tendon
- Preparation of the bony bed at the lesser tuberosity
- Reconstruction of the cuff tear with either single-row or double-row suture bridge technique. Transosseous techniques can be performed.

1.6.8.1 Rehabilitation

The rehabilitation program addresses the fixed subscapularis tendon. In the first 6 weeks any stress on this fixation should be avoided, giving a range of motion of abduction up to 90° and external rotation up to 0° (Table 1.10).

1.6.8.2 Results

It is shown that arthroscopic repair of the subscapularis tendon can lead to good or excellent results in most cases. However, open subscapularis repair is commonly performed and has proven to be sufficient over the years [38]. A recent meta-analysis conducted by Mall et al. demonstrates comparable results after arthroscopic and open subscapularis repair. The mean postoperative Constant score was 88.1 points [33]. In both procedures, concomitant treatments such as biceps tenodesis were frequently performed. Biceps tenodesis was observed in 54.8 %, followed by biceps tenotomy and biceps recentering. Healing was reported in 90–95 % of all patients.

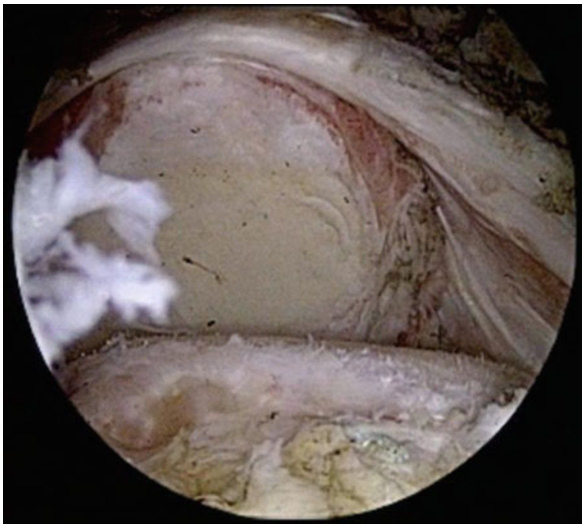

Fig. 1.7 Massive posterosuperior tear. Arthroscopic view from lateral portal

1.6.9 Massive Rotator Cuff Tears

1.6.9.1 Indication

- Symptomatic tears

1.6.9.2 Contraindication

- Stiff shoulder/frozen shoulder
- Fatty degeneration
- Acromiohumeral distance less than 5 mm

1.6.9.3 Positioning

- Beach chair (arthroscopic, mini-open, and open repair)
- Lateral decubitus position (arthroscopic repair)

1.6.9.4 Stepwise Technique

Open, mini-open, and arthroscopic cuff repair are comparable to the above-mentioned technique.

In cases of arthroscopic procedures, it is recommended to switch the optic even in the lateral portal in order to access a frontal view of the cuff tear. It is crucial to evaluate the method of closure properly inasmuch as only a few cuff tears can be closed with a straight lateral pull maneuver (Fig. 1.7).

1.6.9.5 Results

Denard et al. published a study pointing out the importance of performing a double-row fixation whenever possible in this population. They reported a good or excellent outcome in 78 % of the whole population. Comparing double- with single-row repairs, they found that after double-row repair, UCLA gain was greater and this group was 4.9 times more likely to have a good or excellent result [30]. In cases of massive tears, a partial closure like a margin convergence is a reasonable alternative. This should be considered if a high load remains on the repair even after an excessive tissue release. It is well demonstrated that functional repair of the force couple gives good results in terms of pain relief, patient satisfaction, and function [35]. Iagulli et al. reported that patients with massive rotator cuff tears had a comparable outcome after partial closure compared with a complete closure using double-row reconstruction [34]. They stressed that the reconstruction of the force couple is crucial. A reconstructed force couple is likewise responsible for a good outcome in their population of partial repairs [39, 40].

1.6.9.6 Rehabilitation

See Rehabilitation scheme of the supraspinatus tendon repair (see Table 1.9 and Chap. 1.6.5.2).

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2 Posttraumatic Shoulder Instability

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and Norbert P. Südkamp

2.1 Epidemiology

Traumatic dislocations of the shoulder are frequent. The annual incidence is estimated at 11–24/100,000 [1–3]. Data published by Liavaag documents a higher incidence of shoulder dislocations in Oslo, Norway [4]. They report an incidence of about 56.3/100,000. Men show a 2.6 times higher incidence than women (82.2/100,000 versus 30.9/100,000).

2.2 Injury Pattern

The injury pattern varies depending on the patient's age. In younger patients, injuries of the anterior capsular labrum complex are most common. The following can be distinguished:

- Bankart lesion
- Perthes lesion
- ALPSA lesion
- SLAP lesion
- GLAD lesion
- Bony Bankart lesion
- HAGL lesion (Fig. 2.1)

A Hill-Sachs lesion is another typical injury of the humeral head. It is an impression fracture at the posterosuperior side of the humeral head, indicating a traumatic history of the anterior shoulder dislocation. In contrast, a reversed Hill-Sachs lesion occurs in the context of a posterior dislocation, typically in association with a convulsion. The reversed Hill-Sachs lesion is located at the anterior side of the humeral head, just in front of the lesser tuberosity.

In the elderly, the injury pattern changes. It becomes more likely to obtain a rotator cuff tear with or without capsulolabral pathology.

The incidence of injuries associated with traumatic shoulder dislocations can be estimated according to Boss et al. [6]. They observed anterior labral lesions in 88 %, Hill-Sachs lesions in 54 %, superior rotator cuff tears in 22 %, tears of the subscapularis tendon in 16 %, lesions of the long head of the biceps in 10 %, SLAP lesions in 11 %, and fractures of the greater tuberosity in 4 %. If there is no intraoperative evidence of a Bankart lesion or one of its equivalents after traumatic shoulder dislocation, one should be alert for a HAGL lesion. HAGL lesions occur in up to 9 % according to Bui-Mansfield [7] (Figs. 2.2 and 2.3).

2.3 Diagnostic Procedures

A precise history and clinical examination provides valuable information, but, determination of the neurovascular status is of greatest importance. In particular, the status of the axillary nerve and the brachial plexus must be examined and documented.

It is also crucial to obtain "true" a.p. X-rays of the shoulder in order to detect a displaced shoulder. This kind of view tilts the X-ray beam in the line of the glenohumeral joint space. Any double contour around the glenoid is indicative of a displacement. An outlet view and/or an axillary view verify the displacement.

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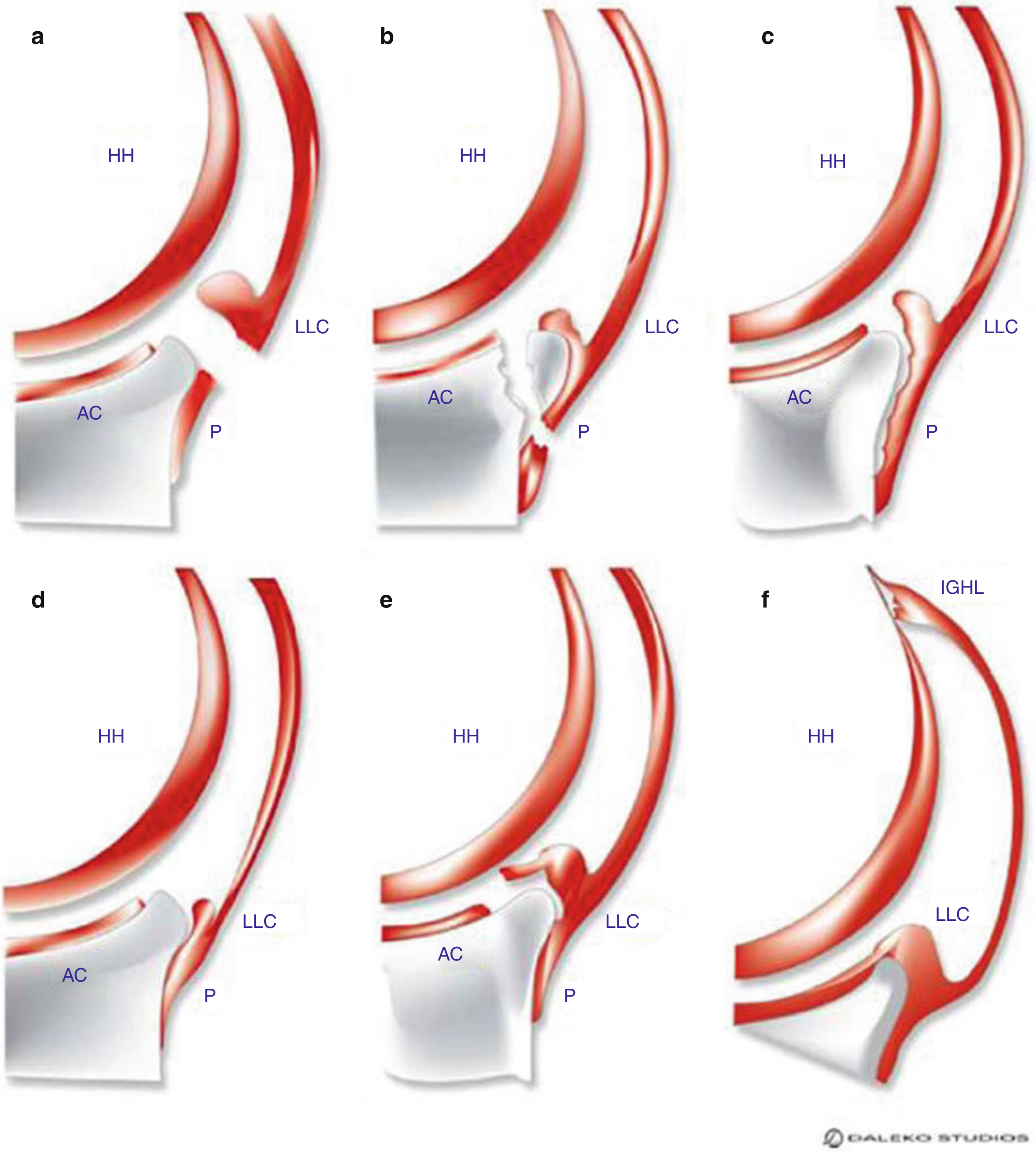

Fig. 2.1 Classification of Bankart and Bankart variant lesions according to Woertler [5]. (**a**) Bankart lesion, (**b**) bony Bankart lesion, (**c**) Perthes lesion, (**d**) ALPSA (anterior labro-ligamentous periosteal sleeve avulsion) lesion, (**e**) GLAD (glenolabral articular disruption) lesion, (**f**) HAGL (humeral avulsion of glenohumeral ligaments) lesion. *LLC* anteroinferior labro-ligamentous complex, *P* scapular periosteum, *HH* humeral head, *AC* articular cartilage of glenoid, *IGHL* inferior glenohumeral ligament

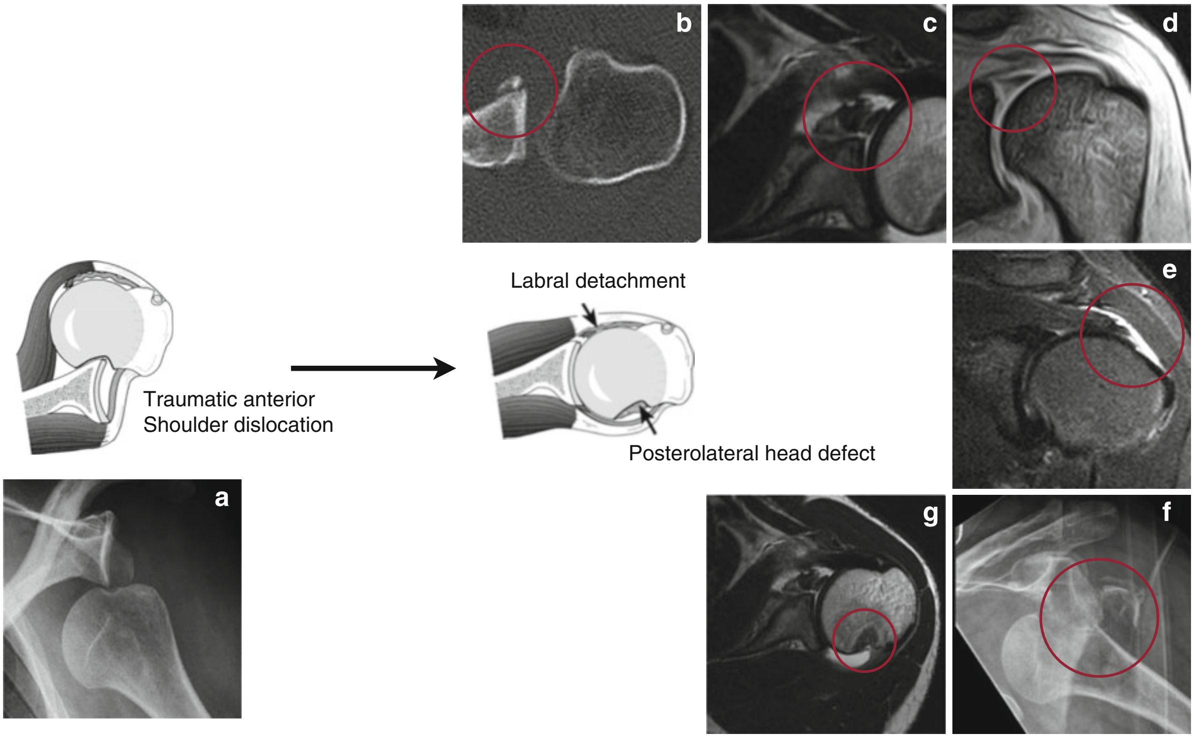

Fig. 2.2 Injury pattern after traumatic anterior shoulder dislocation. (**a**) Anterior shoulder dislocation. (**b**) Bony Bankart lesion. (**c**) Anterior Bankart lesion. (**d**) SLAP lesion. (**e**) Superior rotator cuff tear. (**f**) Fracture of the greater tuberosity. (**g**) Hill-Sachs lesion

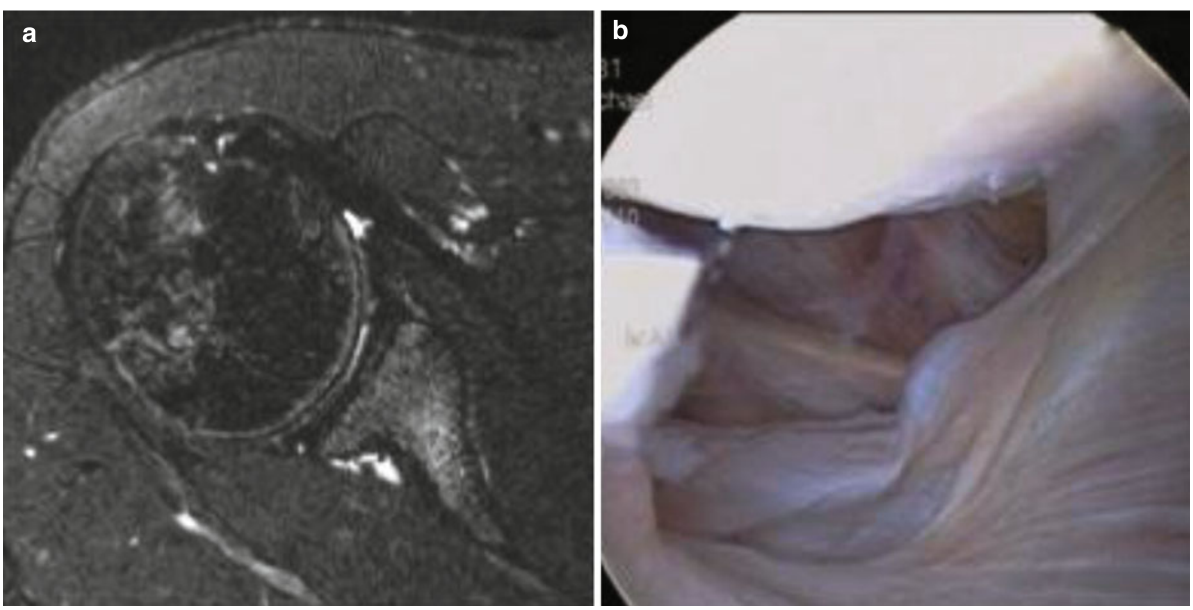

Fig. 2.3 HAGL-lesion. (**a**) Axial sequence of MRI. (**b**) Intraoperative picture

At this point in time, additional imaging procedures are not typically needed. If there is any sign of a fracture dislocation or locked dislocation, an additional CT scan is recommended, especially if a foreseen surgery becomes more likely.

After a reduction, a new clinical examination and imaging is necessary to document the successful reduction and to exclude any complications.

Further diagnostics are needed to estimate the degree of instability, especially the whole injury pattern. The gold standard is MRI of the shoulder. The MRI is useful detecting any capsulolabral injuries, injuries of the long head of the biceps, including its anchor, or the rotator cuff. It is also valuable to estimating bony and chondral lesions. Typically, an arthro MRI is not needed in the acute setting because the hemarthrosis provides sufficient contrasting of the intraarticular structures. In delayed or chronic situations, an arthro MRI is recommended to more precisely evaluate the capsulolabral injury, biceps anchor (SLAP lesions), and integrity of the rotator cuff. If there is an engaging Hill-Sachs lesion, bony Bankart lesion and/or glenoidal bone loss situation, an additional CT scan provides valuable further information. Glenoidal dysplasias and rotational deformity can also be detected using a CT scan. At least in the German-speaking countries, an arthro CT scan is not done routinely.

2.4 Initial Reduction of the Shoulder

There are many methods known for reducing a displaced shoulder. Even today, the painful and brusque procedures of Arlt and Hippokrates remain widespread. These are accompanied by a relatively high complication rate. Hence, they should no longer be applied in the clinical setting. Here, gentle and painless reduction techniques have proved themselves, for example, the technique of Stimson with or without manipulation of the scapula. Using this kind of technique, the patient is placed in a prone position with the affected arm hanging freely. A prospective cohort study published by Pishbin describes 112 consecutive anterior shoulder dislocations in 111 patients. The primary success rate was 87.5 % without any medications [8]. The total success rate after a recurrent attempt using medications was 97.3 %.

2.5 Nonoperative Treatment

Nonoperative treatment is still a well-accepted treatment option. The outcome correlates with the injury pattern, the patient's age, and gender [9–11]. The outcome, especially the recurrence rate after nonoperative treatment, is significantly worse in patients younger than 30 years. Young men have a significantly higher risk than women of the same age. If a recurrent dislocation occurs, the cumulative risk can be estimated at 85 % within the first two post-traumatic years [10]. Hovelius reported his long-term results after nonoperative treatment of traumatic shoulder dislocations in patients younger than 40 years [12]. Forty-three percent had not re-dislocated over time. Again, there was a strong relationship to the patients' age. In patients older than 30 years, 73 % suffer no further shoulder dislocation. Just 14 % achieved surgical stabilization for remaining instability. On the other hand, in patients between ages 12 and 22 years only 28 % were nonrecurrent, 20 % became stable over time, 12 % dislocated recurrently, and 40 % required a surgical stabilization.

The period of immobilization has no significant influence on recurrent instability [9, 13–15]. Neither Hovelius nor Kiviluoto were able to detect any significant benefit in patients younger than 30 years when treating patients nonoperatively in internal rotation for less than 1 week or longer than 3 weeks. Therefore, it is recommended to immobilize the shoulder no longer than 3 weeks, just for pain release in order to prevent posttraumatic shoulder stiffness.

Whether to immobilize the shoulder in internal rotation or in external rotation/abduction remains a matter of debate. Itoi first described beneficial effects in external rotation and abduction. This was confirmed by biomechanical, MRI, and arthroscopic observations [16–18]. The capsulolabral complex gets close contact to the anterior glenoid in abduction/external rotation. Thereby, the best position can be achieved in 30° abduction and 60° external rotation. In addition, several prospective clinical studies show a lower recurrence rate after treatment in this position. However, it is crucial to obtain compliant patients, who must wear a bulky orthesis. This might be the reason why other prospective randomized studies show heterogeneous results. While Itoi and Liavaag initially showed significantly better results in external rotation [11, 19], later reports failed to do so over time [20].

2.6 Surgical Treatment

The goal of surgical treatment is to achieve a stable shoulder and to restore the initial shoulder function. To do so, it is crucial to address the underlying pathology. As mentioned above, this is strongly age dependent. Arguments that must be considered include:

- Occurrence of additional pathologies (i.e., intra- and/or periarticular fractures, SLAP lesions, rotator cuff tears, lesions of the rotator interval)
- Size of the glenoidal and/or humeral bony defect
- Location of capsular injuries (HAGL lesion)

These pathologies result in a higher likelihood of recurrence and/or impaired shoulder function and should indicate surgical treatment. In the absence of these pathologies, surgery becomes relative. The indication is based on the results of nonoperative treatment, which is age and gender dependent. It seems reasonable to recommend surgery in young males, regardless of their activity level, in order to lower the recurrence rate from approximately 80 % to approximately 5 %. However, in women older than 40 years a recommendation of surgery is less certain.

Even absolute contraindications for surgery diminish over time. There are patient-related factors that must be carefully considered because of the high risk of peri- and/or postoperative complications, including:

- Co-morbidity of the patient (e.g., medically unstable patient)
- Lack of compliance of the patient (e.g., chronic alcoholism, psychiatric diseases, uncontrolled seizure disorder)
- Collagen disorders (e.g., Ehler–Danlos syndrome, Marfan syndrome)
- Secondary gain or voluntary subluxation

2.7 Anterior Soft-Tissue Stabilization

Anterior soft-tissue stabilization addresses the anterior capsulolabral pathology. Indication for surgery is given if the amount of bone loss does not exceed a specific size. It is well accepted that a bony deficiency of approximately 25 % on the glenoidal side and approximately 30 % on the humeral side leads to a significantly higher rate of recurrence and should therefore be addressed. Otherwise, the Bankart repair is the classic procedure and is generally performed arthroscopically. From the evidence-based literature, arthroscopic Bankart repair may be considered as the new gold standard [21]. Bankart repair can be performed with or without an additional capsular shift. For fixation of the capsulolabral complex, several methods have been used, including staples, tacks, and transosseous sutures, but these have been accompanied by an unacceptably high rate of recurrence. Today, suture anchors or knotless anchors are well accepted [22]. Modern arthroscopic Bankart repairs are characterized by the following three criteria [21, 23]:

- Use of at least three anchor systems
- Addressing of capsular laxity by anterior shift of capsular plication
- Treatment of concomitant intraarticular pathologies (e.g., lesions of the rotator interval, SLAP lesions)

2.8 Arthroscopic Bankart Repair

2.8.1 Positioning

- Lateral decubitus
- Beach chair

2.8.2 Typical Steps of the Procedure

- Diagnostic arthroscopy
- Creation of one optic (posterior) and two working portals (anterior and anterosuperior)
- Mobilization of anterior capsulolabral complex until subscapularis becomes visible
- If necessary, inferior capsular incision for later capsular shift
- Debridement of anterior chondral border
- Fixation of anterior capsulolabral complex using shuttle devices and suture anchors

2.8.3 Tips and Tricks

- Changing the optic into the anterosuperior portal achieves better visualization of the anterior glenoid neck. This becomes useful for mobilization of the capsulolabral complex, especially for ALPSA lesions.
- A deep anterior trans-subscapular portal might be useful to fix the inferior capsulolabral complex.

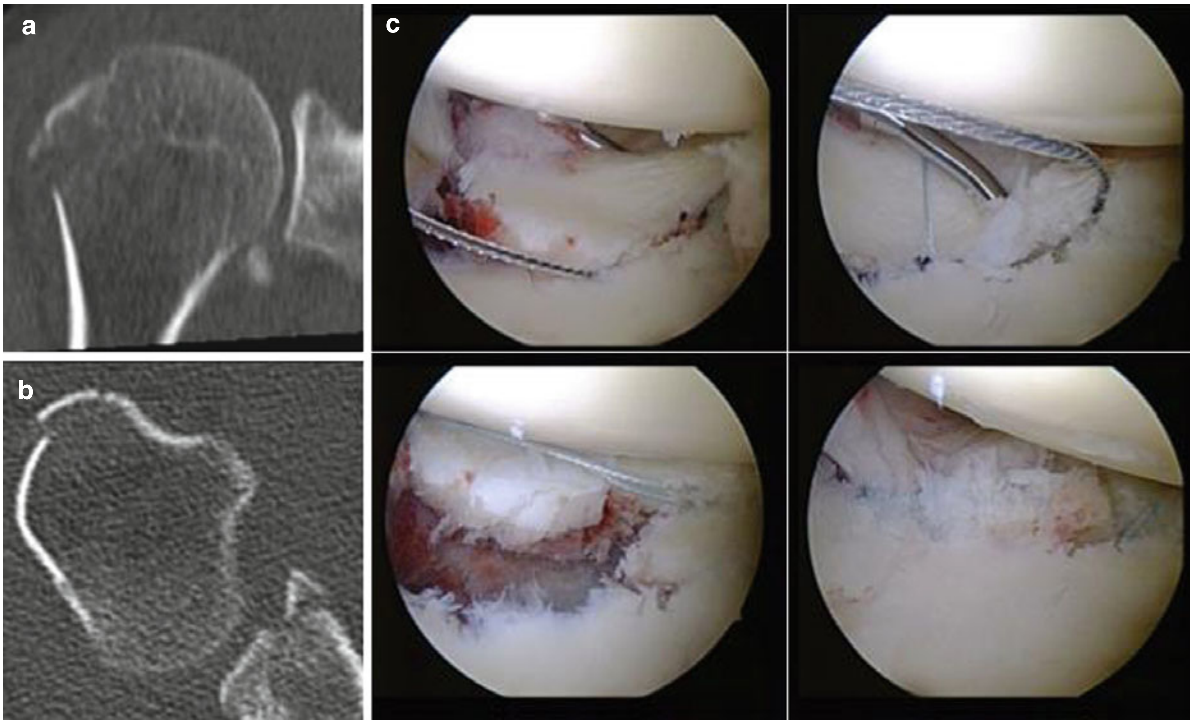

Fig. 2.4 Arthroscopic repair of a bony Bankart lesion. (**a**, **b**) Preoperative CT scan demonstrating an anterior bony Bankart lesion. (**c**) Stepwise arthroscopic fixation of the bony Bankart lesion using suture anchors

- A modified intraarticular Caspari technique might be useful to perform a sufficient inferior capsular shift.
- An arthroscopic Bankart repair is also useful to address bony Bankart fragments.

2.8.4 Results

With respect to the criteria of modern arthroscopic Bankart repair, equivalent rates of recurrence, better functional outcomes, and less morbidity may be achieved compared with open Bankart repair [21, 24]. The recurrence rate can be lowered to 0–6 % [21, 25–27]. Compared with open Bankart repair, several advantages are obvious [28–31]:

- Lower perioperative morbidity
- Less impaired postoperative shoulder function (i.e., less external rotation deficiency)
- No lesions of subscapularis musculotendinous unit
- Ability to address intraarticular pathologies
- Less postoperative pain (Figs. 2.4 and 2.5)

2.9 Bone Transfer

Indication for bone transfer is given if there is a relevant bone loss either at the glenoid and/or at the humerus. In order to judge the glenoidal bone loss, it is useful to evaluate parasagittal sectional images of the glenoid either in CT scan or MRI. A circle can cover the inferior glenoidal surface. In case of a bone loss, a segment of the circle is missing. The size of this defect can be estimated using several methods–the length of the segment's base, its height, or the including angle. Using a digital image viewer the defect's calculation becomes precise [32, 33].

It is well known that the recurrence rate increases significantly if an anterior bone loss is treated only with a soft-tissue repair. A bone transfer is recommended. There are several procedures in use. Anatomic procedures are distinguished from extra-anatomic procedures. Anatomic procedures can be summarized as an autogenous bone-block transfer, typically taken from the iliac crest. This bone-block can be fixed using screws, absorbable tacks, or implant-free (press fit) in the technique according to Resch. These procedures

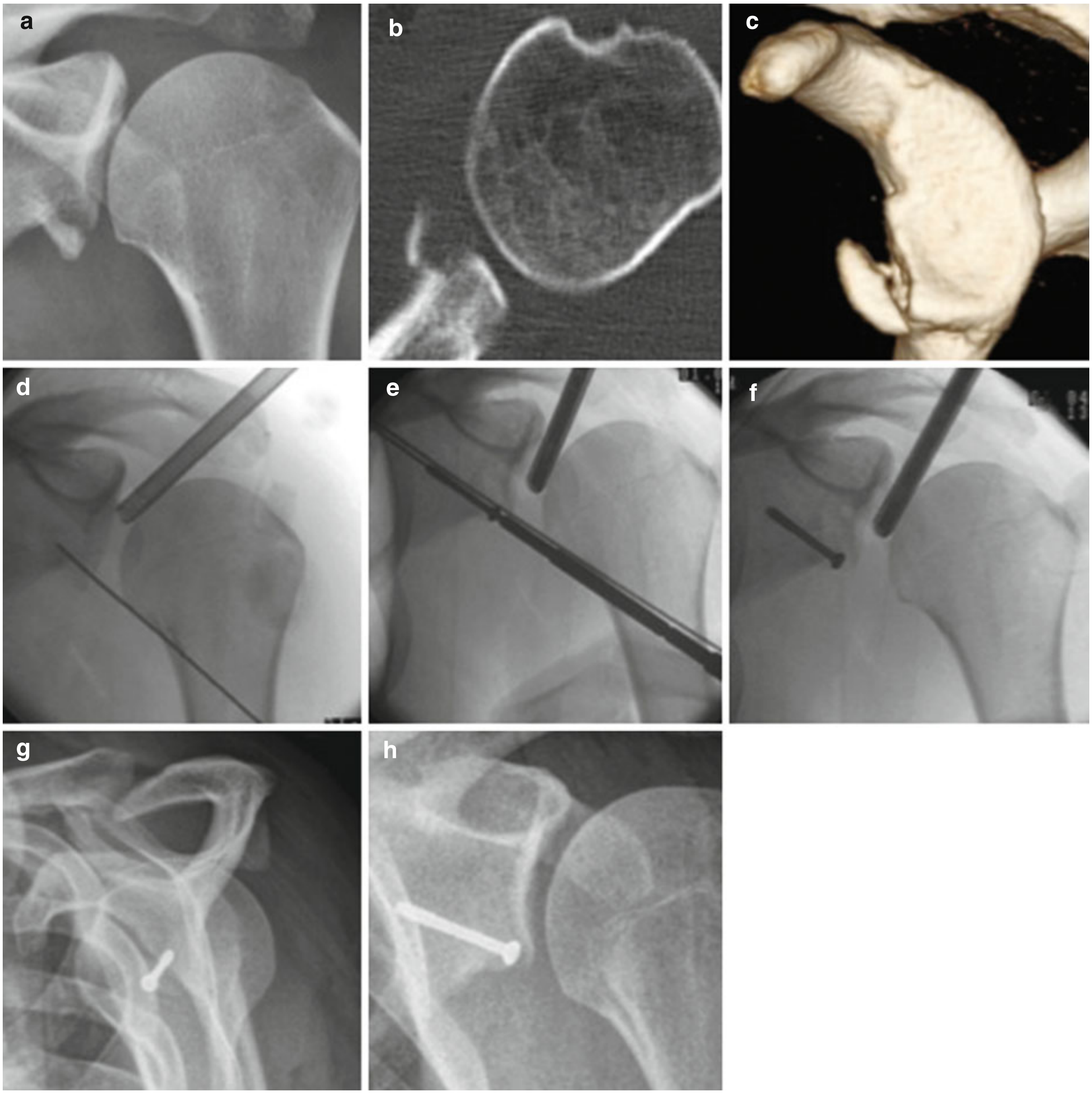

Fig. 2.5 Arthroscopic guided screw fixation of an anterior Bankart fracture. Preoperative diagnostic using (**a**) plain X-ray. (**b**) axial CT-scan. (**c**) 3D-volume rendering of CT scans. (**d–f**) Intraoperative X-rays demonstrating arthroscopic guided screw fixation. (**g**, **h**) 6 months postoperative controls showing anatomic healing of the anterior Bankart fracture

can be accomplished arthroscopically as well [34]. Extra-anatomic procedures are mainly the technique according to Latarjet, where the tip of the coracoid is transferred to the anterior glenoid via a horizontal subscapularis split. This can be also performed arthroscopically. In contrast to the anatomic procedures, the Latarjet procedure provides a beneficial sling effect. The short flexors act against the anteroinferior dislocation forces.

2.10 Hill-Sachs Lesion

Hill-Sachs lesions typically indicate the traumatic nature of a shoulder dislocation. They are also seen in recurrent shoulder dislocations. They occur as a result of a direct impact of the anterior glenoid rim against the posterolateral humeral head. The size of the Hill-Sachs defect varies from bone bruises, which are nicely visualized in MRI, to huge, engaging defects. They can be classified according to Calandra [35]. Grade I lesions are pure chondral lesions limited by the subchondral bone plate. They do not penetrate the subchondral bone plate. Grade II lesions penetrate the subchondral bone plate. Grade III lesions encompass huge osteochondral defects. Hill-Sachs lesions can engage depending on their size and location. Central grade III lesions tend to engage typically. They can also cause persistent instability after exclusive Bankart repair.

The size of Hill-Sachs lesions can be estimated with the help of plain X-rays, CT scans, and MRI. Axial views of the defect's perimeter can be set in correlation to the total perimeter of the humeral head. The defect size can be also estimated in relation to the humeral head's radius. Biomechanical studies show that a defect size of about 5/8 of the humeral head's radius significantly decreases the glenohumeral stability in ABER position [36]. The location of the Hill-Sachs lesion is also important in determining recurrent instability. Central defects, especially those running parallel to the anterior glenoid rim, are associated with high rates of recurrent instability.

Therapeutic recommendations are offered mainly in relation to the defect size [37, 38]:

- *Hill-Sachs lesions up to 20 %*: Mainly nonoperative treatment. It is sufficient to address the anterior capsulolabral pathology using soft-tissue stabilization with or without an inferior capsular shift. Alternatively, bone transfers can be considered.
- *Hill-Sachs lesions of 20–40 %*: It is recommended also to address the Hill-Sachs-lesion. A remplissage can be considered. This includes an extra-anatomic procedure transferring the posterior capsule and the infraspinatus into the Hill-Sachs defect. The former intraarticular defect becomes thereby an extraarticular defect. The remplissage can also be performed arthroscopically [38–43]. A postoperatively suspected external rotation deficiency is uncommon. Purchase demonstrates a 7 % recurrence rate using arthroscopic remplissage in combination with an arthroscopic Bankart repair without any significant complications or any external rotation deficiency [38]. Similar results are provided by Nourissat. He published a prospective randomized study demonstrating that the remplissage technique does not alter the range of motion of the shoulder compared with the Bankart procedure alone. However, one-third of patients did experience posterosuperior pain [42]. The recurrence was 6.25 % in both groups.

  Alternatively, one can lift the Hill-Sachs lesion and line them up with cancellous bone or other bone substitutes, especially if the Hill-Sachs lesions are fresh. This can be performed with open surgery or arthroscopically and is more common in order to address reversed Hill-Sachs lesions [44]. Limitations are seen in defects larger than 40 % [45].

  In chronic Hill-Sachs lesions up to 30 %, an autologous bone transfer can be considered, which is cut in the shape of the humeral head and fixed with either mini Herbert screws or absorbable tacks (e.g., PolyPins) [46, 47].
- *Hill-Sachs lesions more than 40 %*: In Hill-Sachs-lesions of greater than 40 %, either a bone transfer or a hemiarthroplasty can be considered. The latter is especially recommended in the elderly [48, 49] (Figs. 2.6 and 2.7).

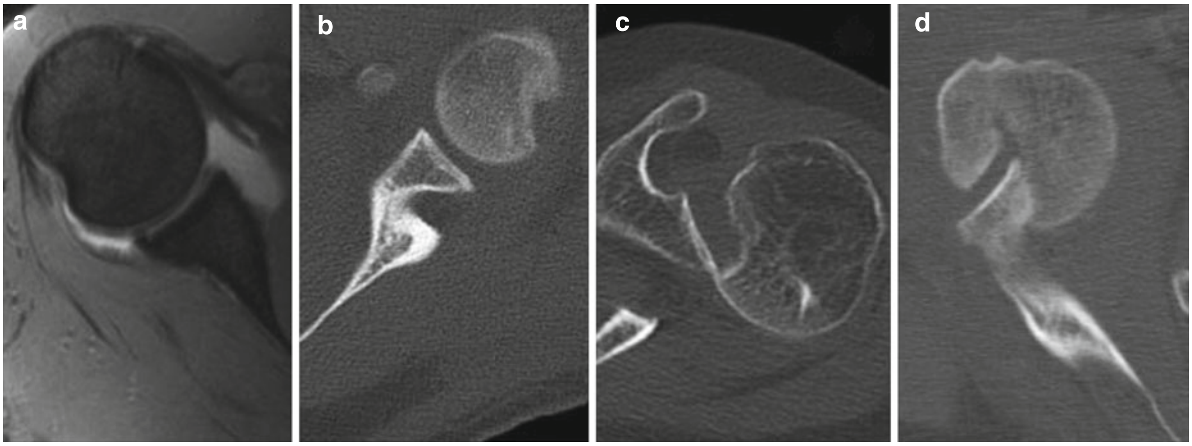

Fig. 2.6 Different types of Hill-Sachs lesions. (**a**) Anterior Hill-Sachs lesion less than 20 %. (**b**) Reversed Hill-Sachs lesion. (**c**) Engaging Hill-Sachs lesion. (**d**) Locked Hill-Sachs lesion

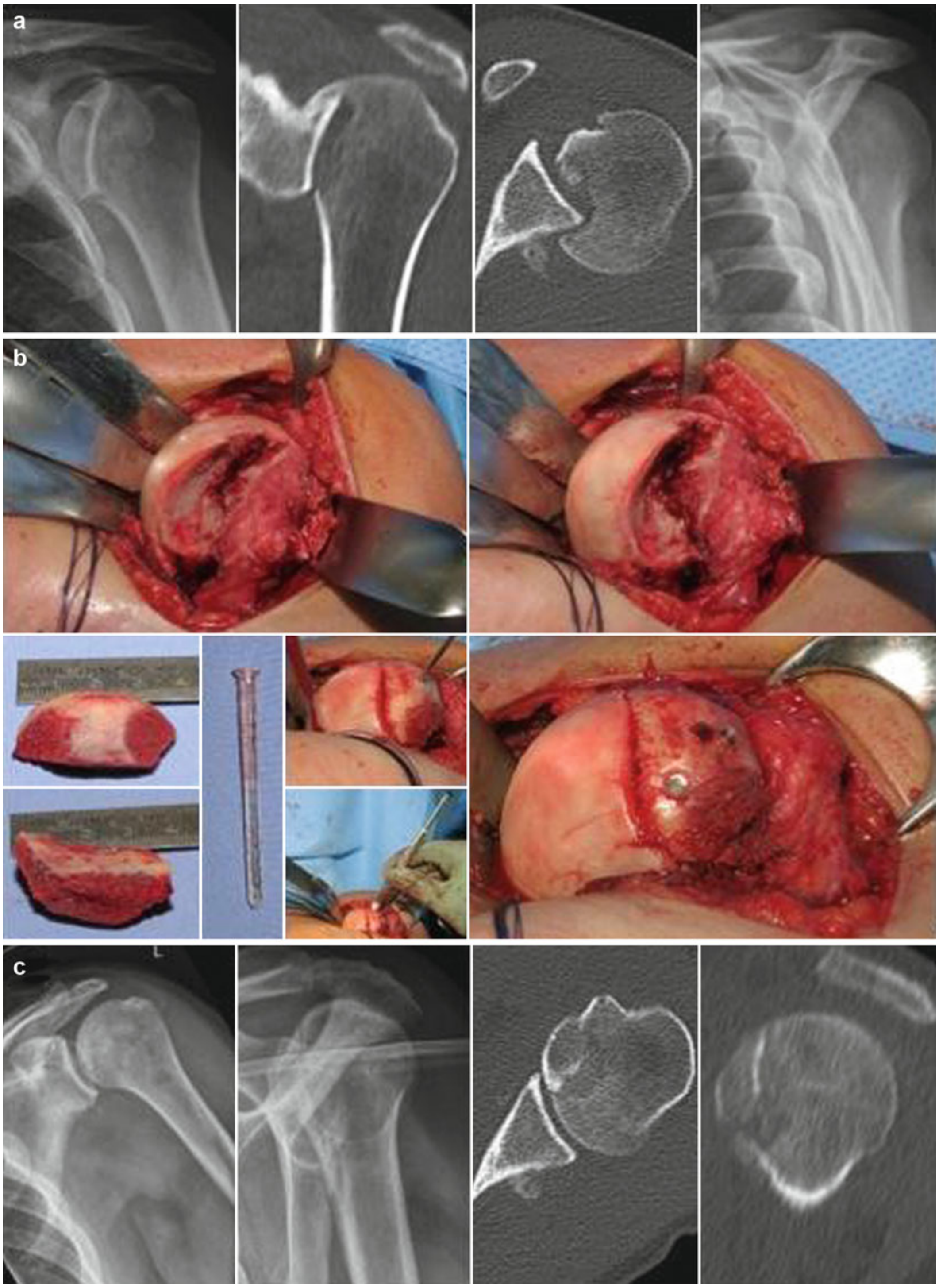

Fig. 2.7 Bone transfer for treatment of a reversed Hill-Sachs lesion larger than 40 % using (**a**) preoperative X-rays and CT scan revealing a chronic reversed Hill-Sachs lesion, and (**b**) intraoperative pictures demonstrating the bone transfer. Graft is taken from the iliac crest and fixed with absorbable pins (PolyPin®). (**c**) Postoperative controls after 2 days and 6 months

2.11 Rotator Cuff Tears

Rotator cuff tears are typically seen in patients older than 40 years having a traumatic shoulder dislocation. This cuff tear is usually a massive tear, which is not only painful but also impedes shoulder function and glenohumeral stability. Therefore, they should be addressed by surgery. Most often, rotator cuff repair is performed arthroscopically, with or without an anterior Bankart repair. Further information is provided in a separate chapter.

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Proximal Humeral Fractures

3

Martin Jaeger, Kaywan Izadpanah,
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3.1 Introduction

Proximal humeral fractures are quite frequent, especially in elderly females with osteopenic bone structure. With precise diagnostics and a consequent classification of the fracture, it is possible to define an individual treatment protocol. In doing so, it is helpful to understand the individual pathomechanisms leading to the fracture pattern that must be addressed. Even today, proximal humeral fractures are treated mostly nonoperatively. Operative treatment is challenging. In order to cover the entire variety of fractures it is necessary to perform all kinds of osteosynthesis, including K-wires, nails, plates, and both anatomic and inverse fracture prostheses.

3.2 Epidemiology

The proximal humerus is one of the most frequently seen fracture locations. These fractures are the third most common in the elderly, after hip and wrist fractures. The incidence in Europe can be estimated between 63/105,000 and 342/100,000 [1–3]. This depends on age and gender and is often associated with osteopenia. Females older than 80 years have the highest incidence, with approx. 1,150/100,000 [2]. Following the calculation of Palvanen, it can be concluded that the incidence will increase up to three times in the next three decades [3].

3.3 Etiology

Proximal humeral fractures can be seen isolated or in combination with other injuries. The high-energy traumas mostly seen in the younger patients should be distinguished from low-energy traumas, which occur mainly in the elderly. High-energy traumas result in both a severe soft-tissue injury and a severe comminution of the proximal humerus, frequently associated with a polytrauma. The latter results from a simple fall from standing height with the arm either in ab- or adduction. The position of the arm determines the displacement of the humeral head fragment. The pull of the rotator cuff not only separates the tuberosities but also the rotation of the humeral head fragment.

3.4 Classification

Common classifications of proximal humeral fractures are:

- Codman classification
- Neer classification
- AO/ASIF classification
- LEGO-Codman classification according to Hertel

To date, there is no single classification system in common use. A classification should be intuitive, comprehensive, and have clinical relevance. It is obvious that the more complex a classification becomes, the lower the inter- and intra-observer reliability [4].

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All four above-mentioned classification systems distinguish between the four main fragments: the humeral head fragment, the lesser tuberosity, the greater tuberosity, and the shaft fragment. Seventy-five years ago, Codman introduced his descriptive classification separating the above-mentioned major fragments when there is a displacement larger than 1 cm or an angulation more than 45°. In contrast, the Neer classification provides a classification concept describing the force of the distracting muscle pull of the rotator cuff acting on the four major fragments. Anterior and posterior dislocation fractures and head splitting fractures are also described. The AO/ASIF classification is well-accepted worldwide. Proximal humeral fractures are described by the number code "11". The following letter codes indicate extraarticular unifocal = a, extraarticular bifocal = b, and intraarticular fractures = c. The LEGO-Codman classification according to Hertel [5] offers a comprehensive system with high clinical relevance. It is characterized with:

- Five basic questions defining the main fracture lines
- Seven additional questions defining accessory criteria in order to describe the fracture, including:
  - Length of the posteromedial metaphyseal extension
  - Displacement of the shaft with respect to the head
  - Displacement of the tuberosities with respect to the head
  - Angular displacement of the head
  - Glenohumeral dislocation
  - Head impression fracture
  - Head-split component

Research provided by Majed demonstrates that the overall interobserver reliability shows slight to moderate agreements. However, the LEGO-Codman classification has the most reliable interobserver scores compared with the others [6].

3.5 Diagnostic Procedures

Diagnosis is based on plain X-rays, with at least two (e.g., true ap and outlet view), if not three plains. The axillary view is sometimes challenging to achieve because abduction is painful. In these cases, the Valpeau view is recommended. Additional CT scans are helpful for gathering additional fracture information. In combination with plain X-rays, several questions have to be answered:

- The exact fracture pattern, including position of the head and tuberosities
- Head-splitting component
- Bone quality
- Comminution
- Signs of humeral head ischemia
- Additional injuries (e.g., glenoid fractures, coracoid fractures, acromion fractures)

Even with the availability of sectional images, one should still rely on plain X-rays inasmuch as they offer the most important information. Ultrasound and MRI are, in general, not necessary. In order to rule out additional injuries, they can be helpful in some specific situations.

A precise neurological and vascular evaluation is mandatory, especially of the axillary nerve and/or brachial plexus if a glenohumeral dislocation is present.

3.6 Risk of Osteonecrosis

Initial radiographs can estimate the risk of osteonecrosis. An anatomic neck fracture, a short posteromedial metaphyseal extension of the humeral head less than 8 mm, and a ruptured medial hinge are powerful predictors. All three items together are able to predict an ischemia of the humeral head with an accuracy of 97 % [7]. However, not every initial ischemia has to develop a humeral head necrosis [8]. According to Gerber, not every posttraumatic avascular necrosis becomes symptomatic and some can be well tolerated over many years without requirement of a humeral head replacement. If needed, this can be done with good results if the tuberosities have healed in an anatomic position [9, 10].

3.7 Treatment

3.7.1 Nonoperative Treatment

3.7.1.1 Indication

Nearly every proximal humeral fracture can potentially be treated conservatively. This is explained by a high rate of complications associated with osteosynthesis of the proximal humerus, independent of the kind of implant, fracture pattern, and bone quality.

The more severe the fractures are, the poorer the results are, even with osteosynthesis or arthroplasty; the latter results in a higher rate of complications.

3.7.1.2 Rehabilitation

The injured shoulder is typically immobilized in a sling for 3 weeks followed by active assisted physiotherapy and pendulum exercises for the following 3 weeks. After the sixth week active physiotherapy is performed.

3.7.1.3 Results

Even today, nonoperative therapy represents the main and most frequently used treatment option. Its incidence of nonunion is low, accounting all types of fractures. According to Court-Brown, nonunions amount to approximately 1.1 % [11]. Risk factors for mal- and nonunions are a comminuted metaphysis and a displacement of the humeral shaft in respect to the humeral head of 33–100 %. In these cases, the incidence of nonunions increases up to 8 % and 10 %, respectively. Less complex fracture types such as 11A2, 11A3, and 11B1 according to AO/ASIF result in a good clinical outcome with mean Constant scores of 64/100, 65/100, and 72/100, respectively [12]. Iyengar published a meta-analysis involving 650 proximal humeral fractures in 12 studies, all treated nonoperatively. There were 317 one-part fractures, 165 two-part fractures, 137 three-part fractures, and 31 four-part fractures involved. The mean follow-up was 45 months. Union was seen in 98 %, and the mean Constant score of all fractures was remarkably high, with 72/100 points. Incidence of complication was calculated at 13 %, mainly seen in varus malunions [13].

Today, there is also level-I evidence available, provided by two prospective randomized trials, that conservative therapy is at least not inferior compared with operative treatment in more complex fractures, for example, displaced three- and four-part fractures [14] and all types of three-part fractures [15]. Constant scores are comparable in both groups without any significant difference (58/100 points for nonoperative therapy; 61/100 points for plating using Philos®). However, the operative groups resulted in a significantly higher rate of complications, requiring second surgery in up to 30 % and consuming much higher costs. Stressing the benefits of nonoperative treatment, Sanders published a matched-paired study involving 36 proximal humeral fractures, with mean patient age of 61 years and a mean follow-up of 1 year [16]. In this study, the nonoperative group resulted in a significantly better range of movement compared with plating and a significantly better postoperative function measured with the ASES score (82.5/100 versus 71.6/100, respectively).

3.7.2 Operative Treatment

3.7.2.1 General Considerations

Operative treatment is supposed to correct fracture displacement and to achieve higher stability in order to gain earlier and/or better shoulder function. Doing so, it is crucial to achieve a proper, in most aspects, anatomically reduction. The key fragment is the humeral head. This fragment has to be managed gently and precisely at the same time. The goal is to place the humeral head in the correct inclination and torsion [17]. This is necessary to restore the proper space for the tuberosities. If the humeral head is not placed at its original position, there is no way to reduce the tuberosities adequately underneath it, resulting in either lower stability of the construct and/or impingement problems [7, 17]. Therefore, any kind of manipulation must be performed gently. The osteopenic humeral head of elderly females and their tuberosities are especially fragile and do not forgive rough maneuvers with forceps or elevators. Indirect procedures using sutures are preferred.

3.7.2.2 Timing

Proximal humeral fractures are rarely urgent situations requiring immediate surgery. If surgery is foreseen, it can usually be performed within 7–10 days after trauma. Immediate surgery is recommended in the following cases:

- Open fractures
- Glenohumeral dislocation
- Ischemic humeral head if osteosynthesis is attempted
- Neurovascular co-injuries

3.7.2.3 Positioning

In the surgical treatment of proximal humeral fractures, two positions are commonly used:

- Beach-chair position
- Supine position

The beach-chair position is usable in almost all cases. It is mainly employed if an anterolateral or lateral approach is chosen. It offers excellent access to the whole shoulder, in contrast to the supine position, and also to the lateral and some posterior parts. The disadvantages are the time-consuming positioning, a potential risk of traction lesions of the brachial plexus, and gravity forcing the humeral shaft in a natural posterior displacement that must be actively counterforced.

The supine position is a less common placement. The shoulder is typically placed laterally on a shoulder support. Benefits of this positioning are the easy and quick preparation time and the ability to place the humerus on supports, helping to avoid a severe posterior displacement of the shaft. Additionally, it is easier to achieve two perpendicular X-ray planes, especially a transaxillary view, without movement of the arm intraoperatively. This is strongly recommended in order to minimize the rate of primary intraarticular implant malpositioning. It is also possible to convert a primary intended osteosynthesis into a fracture arthroplasty without changing into the beach-chair position.

3.7.3 K-Wires

3.7.3.1 Indication

K-wires are widely used in adolescent proximal humeral fractures but not so much in adults. Resch promoted the semirigid concept in the treatment of osteoporotic proximal humeral fractures introducing the "Resch-Block". It is an extra medullary device fixing two K-wires. The main advantage of this technique is the reduction of load at the bone-metal interface and their ability to allow a controlled, guided impaction of the humeral head [18]. This is important because the fractured humeral head has a strong tendency toward impaction. A further benefit of fixed K-wires is their implanted direction, which is in line with the direction of peak forces according to Bergmann [19].

3.7.3.2 Positioning

Supine and beach-chair position are commonly used.

3.7.3.3 Approach

A closed reduction is typically performed. An open reduction via an anterior or anterolateral approach can also be chosen. The possibility of intraoperative X-ray should be checked precisely.

3.7.3.4 Implant-Related Risks

- K-wire perforations of the humeral head in the progress of a controlled sintering are frequently seen. They can result in early implant removal.
- Injury of the axillary nerve, especially while implantation of the lateral K-wires.
- Injury of the biceps tendon during K-wire insertion from the anterior.

3.7.3.5 Postoperative Rehabilitation

The injured shoulder is typically immobilized in a sling for 3 weeks, followed by slow rehabilitation. The subsequent 3 weeks are characterized by an active assisted physiotherapy. Active movements are usually allowed after 6 weeks.

This rehabilitation program is conservative. Stiff shoulders are rarely seen as long as a closed reduction is performed and the subacromial space was not entered.

3.7.3.6 Results

To date, there are only a few papers published reporting on the outcome of K-wire osteosynthesis [18, 20, 21]. In experienced hands, good to very good results can be achieved in three-part fractures with an average Constant score of 91 % (84–100 %) and without any signs of osteonecrosis at the latest follow-up at 24 months. Even in four-part fractures, the average Constant score was 87 % (75–100 %) in patients who did not need further operation [21, 22].

3.7.4 Nails

3.7.4.1 Indications

The main and recommended indications are two-part surgical neck fractures and slightly displaced three- and four-part fractures. Reduction and fixation is limited in multifragmentary three- and four-part fractures. In these cases, their use should be restricted to experienced hands.

3.7.4.2 Positioning

- Beach-chair position

3.7.4.3 Approach

- Anterolateral approach
- Lateral approach

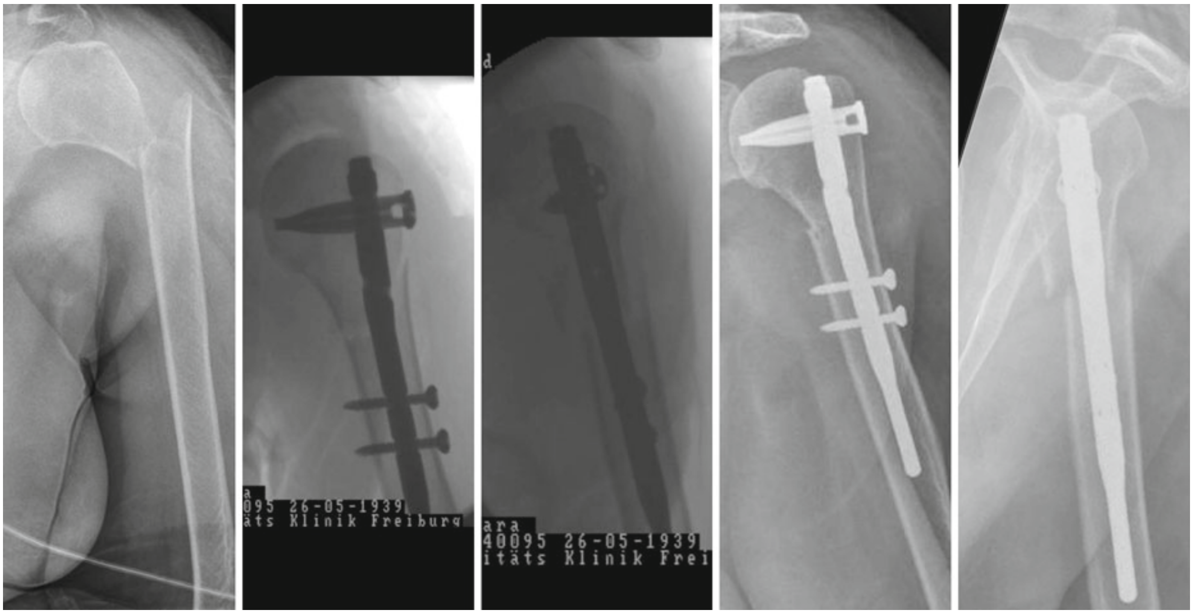

Fig. 3.1 Varus-displaced, surgical neck two-part-fracture of the proximal humerus of a 68-year-old male after a car accident, treated with a proximal humerus nail (Synthes®)

3.7.4.4 Implant-Related Risks

- Malreduction resulting from wrong insertion point of the nail
- Iatrogenic injury of the long head of the biceps tendon
- Intraarticular, primary implant malposition
- Injury of the axillary nerve
- Cuff insufficiency resulting from supraspinatus split and/or insertion in the footprint area

3.7.4.5 Results

In many trials, nails are proven to be superior biomechanically compared with plates. This is especially evident in osteopenic bone quality because the proximal nail is anchored in the best bone stock of the humeral head. It is crucial to access the proper entry point of the nail. Using straight nails, this entry point is projected in the line of the humeral shaft crossing the apex of the humeral head. Particularly in varus-displaced fractures, it is mandatory to reduce the humeral head prior to implantation of the nail. Stay sutures or K-wires used as joysticks are helpful to achieve the proper reduction of the humeral head.

A recent prospective multicenter trial performed by the AO = Arbeitsgemeinschaft für Osteosynthesefragen revealed excellent clinical results using antegrade locking nails. After a follow-up of 1 year, the postoperative absolute Constant score was 75.3/100 points, and the relative Constant score 83.8/100 points. Nonunions were seen in 1 % of all patients. The number of complications and poor clinical outcome measured with the Constant and DASH score was seen more frequently in increasingly complex fracture patterns such as the C-type fractures [23]. These results are confirmed by other authors [24] (Fig. 3.1).

3.7.5 Plates

3.7.5.1 Indications

Plates have a wide spectrum of indications. Even in osteopenic, complex fracture patterns, stable osteosynthesis can be achieved using plates. Today, angular stable locking plates are state-of-the-art. Less complex fractures can be treated by closed reduction and minimally invasive plate osteosynthesis using MIPO techniques. More complex fractures should be addressed by open reduction and lateral plate osteosynthesis. Limitations are poor bone quality, head-splitting fractures, and a medial comminution, especially in varus-displaced fracture types. An additional tension-band suturing is recommended inasmuch as it provides less secondary displacements of the tuberosities.

3.7.5.2 Positioning

- Beach-chair position
- Supine position

3.7.5.3 Approach

- Anterior, deltopectoral approach
- Anterolateral approach
- Lateral approach
- Minimally invasive approach

3.7.5.4 Implant-Related Risks

- Secondary loss of reduction (especially in varus-displaced fractures)
- Primary and secondary intraarticular malposition of screws
- Implant failure
- Injury of the axillary nerve if a lateral or anterolateral approach is chosen
- Iatrogenic injury of the long head of the biceps tendon

3.7.5.5 Results

Successful healing can be achieved with locking plates, even in osteoporotic four-part-fractures (Fig. 3.2). However, it is essential to pay special attention to the following.

- Anatomic reduction
- Proper plate positioning below the greater tuberosity and in line with the shaft axis
- Correct primary screw placement in the humeral head with subchondral bone purchase
- Medial calcar screw support from inferior-lateral to superior-medial in varus-type fractures
- Sutures through the rotator cuff to the plate

A recent prospective multicenter trial conducted by the AO shows an overall good clinical outcome using plates in 346 patients. The individual Constant score reaches values between 85 % and 87 % after 1 year follow-up [22, 25]. Nonunion is seen only in up to 5.8 %. It is remarkable that there was a high unsuspected rate of complications, up to 45 %. According to the systematic review of 791 patients treated with a locking plate, Thanasas confirmed a high incidence of complications. Osteonecrosis occurred in 7.9 %, screw cut-out in 11.6 %, and reoperations in 13.7 % [26]. Analysis of these complications shows that most result from surgical mistakes and are therefore avoidable. This is true for a wrong placement of the plate, especially a too high position resulting in an impingement, and for the primary intraarticular perforation of the screws. To decrease these mistakes, it is recommended to use a supine position, placing the shoulder on small shoulder supports to allow a precise intraoperative X-ray control in two perpendicular views without moving the arm.

Nevertheless, a meta-analysis published by Lanting in 2008 that included 66 studies and 2,155 fractures demonstrated that angularly stable plates seem to be favorable to nails in three- and four-part fractures [24].

Varus displaced humeral head four-part fractures, especially in combination with a medial comminution, are challenging, even today. In these cases, it is advisable to reduce the proximal humerus anatomically and to restore the calcar as precisely as possible. It is proven that a remaining varus angulation of 120° is a strong predictor of a secondary varus collapse with consequent secondary screw cut-out [27]. In addition, it is generally accepted to support the medial column with ascending calcar screws and/or a slight impaction of the humeral head. In cases of a medial comminution, implantation of an intramedullary fibular graft is shown to be beneficial. Augmentation with bone substitutes is disappointing because they do not integrate and are not able to prevent a secondary varus collapse.

Krappinger and colleagues determined several prognostic factors predicting a failure of plate osteosynthesis. These were for patients aged 63 years and older, with poor bone density of less than 95 mg/ccm, a nonanatomical reduction of the proximal humerus, and a lack of restoration of the medial calcar. The risk of failure highly increases in the presence of two or more risk factors [28]. Similar predictors of failure were detected by Südkamp and colleagues in a path analysis of factors for functional outcome at 1 year in 463 proximal humeral fractures [29].

3.7.6 Fracture Arthroplasty

3.7.6.1 Indications

Indications for fracture arthroplasty are mainly given if a stable osteosynthesis is not achievable because of either bad, osteoporotic bone quality and/or comminution of the proximal humerus. The poor bone quality can be estimated by measurements on preoperative CT scans [30] and/or based on the thickness of the metaphyseal cortex

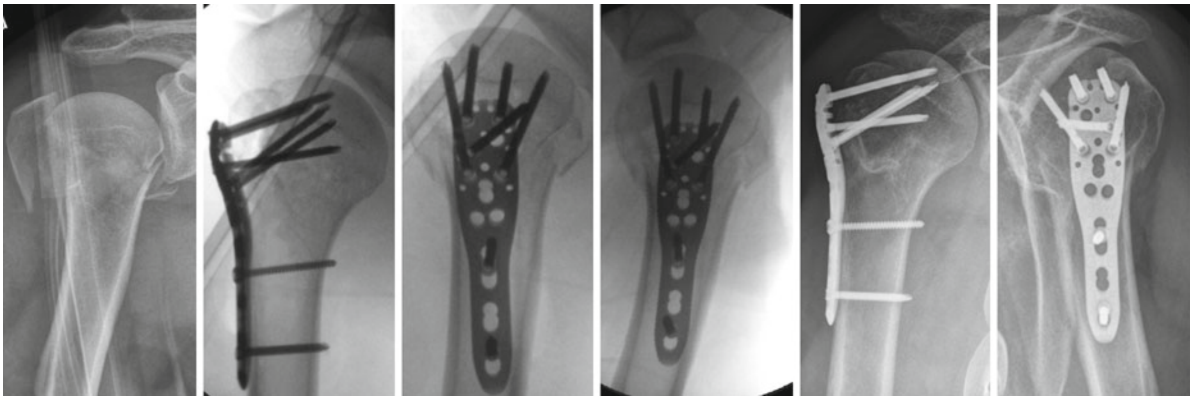

Fig. 3.2 Valgus-displaced humeral head four-part fracture of a 72-year-old male treated with Philos®-plate. (**a**) Preoperative fracture situation, (**b**) the intraoperative result, (**c**) the result 2 days postop, and (**d**) the result at 1 year postop

on plain X-rays. If both the medial and lateral cortex are less than 4 mm in length, severe osteoporosis is obvious [31]. Head-splitting fractures and impression-fractures involving more than 40 % of the humeral head surface are also considered to be treated with a fracture arthroplasty. However, in young patients, an osteosynthesis should be attempted because a secondary fracture arthroplasty in these fracture sequelae achieves better results. Humeral head ischemia should also be considered with care because only the humeral head ischemia seems to be predictable according to the predictors of Hertel [7] but not its consecutive development of an avascular necrosis [32]. This is also underlined by the fact that not every avascular necrosis of the humeral head becomes symptomatic.

In cases of a preexisting cuff-tear arthropathy or massive rotator cuff tear, a reverse shoulder arthroplasty is indicated. It is also suggested by some authors to use reverse shoulder arthroplasty generally in patients aged 75 and above. This recommendation derived from the bad outcome of many anatomic fracture arthroplasties accompanied by a secondary cuff insufficiency because of displaced and/or resorbed tuberosities.

3.7.6.2 Positioning

- Beach-chair position
- If a supine position was chosen when previously attempting an osteosynthesis, it is also possible to convert into a fracture arthroplasty using the supine position

3.7.6.3 Approach

- Anterior, deltopectoral approach (standard)

3.7.6.4 Specific Risks

- Secondary loss of reduction and/or resorption of the tuberosities
- Incorrect implantation of the prosthesis (e.g., retrotorsion, height)
- Incorrect dimension of the prosthesis (e.g., overstuffing)
- Nerve lesion (axillary nerve)
- Infection

3.7.6.5 Results

It is possible to achieve good clinical results, in terms of pain relieve and function, using an anatomical fracture arthroplasty. Hertel shows a main Constant score of 70/100 points [32] (Fig. 3.3). Other authors report less positive results, including a main Constant score of 41/100–64/100 points [33]. It is well known that the outcome strongly depends on the anatomic ingrowth of the tuberosities. Especially in the elderly, a secondary displacement and/or resorption of the tuberosities is frequently seen [34–36]. To decrease this risk, it is crucial to implant the prosthesis in an anatomic position avoiding any overstuffing and to reduce the tuberosities properly. It is also recommended to use autologous bone grafting, retrieving cancellous bone out of the humeral head and using tubercables instead of sutures in order to increase primary fixation. In order to prevent a negative winging effect of the tuberosities, a medial embracing fixation technique should be used.

The reverse fracture arthroplasty seems to be independent of the ingrowth of the tuberosities because the effective moment of the deltoid muscle is increased. In fact, it is still crucial to achieve an ingrowth of the

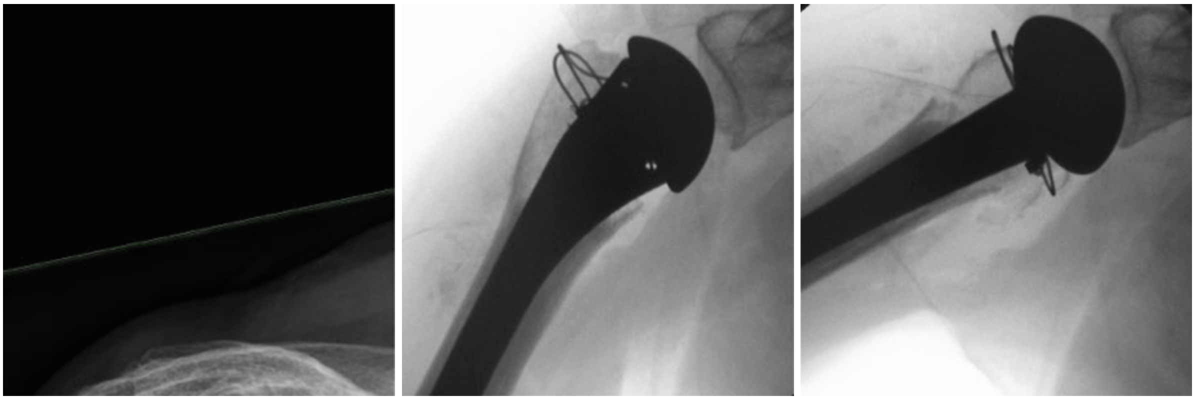

Fig. 3.3 Severely displaced humeral-head four-part fracture of an 86-year-old female resulting from a domestic fall, treated with an anatomic fracture prosthesis (Epoca®)

tuberosities in order to achieve sufficient internal and external motions that are necessary for all daily activities. Until now, it was not possible to state the superiority of reverse fracture arthroplasty in comparison to anatomic fracture arthroplasty measured with the Constant score. Using reverse fracture arthroplasty, a mean Constant score between 53/100 points and 68/100 points can be achieved [37, 38]. Gallinet compared both systems in a matched-pair study in 2009 [39]. Reversed prostheses showed better results in terms of abduction, forward flexion, and Constant score (53/100 points versus 39/100 points, respectively). However, rotation was better with anatomic prostheses. The DASH score was equal in both groups. Typical complications differed significantly. The main complication was an abnormal tuberosity fixation in 17.6 % in the anatomic arthroplasty group and inferior glenoid notching in 93.7 % in the reverse arthroplasty group. According to the study published by Favard, one should use the reverse fracture arthroplasty with care, especially in patients aged less than 75 years [40–42]. Although Favard described a survival rate of reverse prostheses of 89 % after 10 years, taking removal or conversion to a hemi-arthroplasty as an endpoint, it is noteworthy that 72 % of all patients showed a Constant score of 30/100 points or less 10 years postoperatively [43]. This may be explained by a secondary weakness of the deltoid muscle and/or a polyethylene disease.

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Treatment of Acromioclavicular Joint Dislocation

4

Klemens Horst, Thomas Dienstknecht,
and Hans-Christoph Pape

4.1 Epidemiology

Acromioclavicular joint dislocation occurs as a result of an acute traumatic event. Patients are most often young and active in sports. The incidence of acromioclavicular joint separation varies with the sportive activity and can reach up to 20 % in skiing. Altogether, separation of the acromioclavicular joint accounts for 4–6 % of all joint dislocations [1]. Injuries of the shoulder complex are associated with a decreased range of motion and may be followed by serious consequences when diagnosis is delayed or even wrong.

4.2 Anatomy

4.2.1 Bones

The acromioclavicular joint is a diarthrodial joint, built by the acromion on its lateral aspect and the lateral clavicle on its medial margin. A fibrocartilaginous intraarticular disc is located between the osseous segments.

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4.2.2 Ligaments and Fascias

Stability is achieved by the acromioclavicular and coracoclavicular ligaments. The acromioclavicular ligament provides horizontal stability and consists of superior, inferior, anterior, and posterior components. The superior ligament is known to be the strongest, followed by the posterior ligament. The coracoclavicular ligaments (trapezoid and conoid) provide vertical stability and insert 3 cm from the distal end of the clavicle (trapezoid) and 4.5 cm (conoid) from distal end of clavicle on its dorsal margin. Additionally, the capsule as well as deltoid and trapezius fascias act as additional stabilizers [8, 9].

4.2.3 Motion

The acromioclavicular joint accounts for 40 % of scapular movement [2]. While the clavicle rotates nearly 40–50°, only 8 % of the rotation passes the acromioclavicular joint. The majority of motion is caused by the bones, not by the joint itself. The acromioclavicular joint differs anatomically and can be classified by the DePalma classification.

4.3 Classification (Table 4.1)

4.4 Diagnostics

When the patient has suffered from a traumatic event, a direct blow to the adducted arm is frequently described. Bruises and cranial dislocation of the lateral

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Table 4.1 Rockwood classification [2]

Type	Description
Type I:	Sprain of the acromioclavicular or coracoclavicular ligament
Type II:	Subluxation of the acromioclavicular joint associated with a tear of the acromioclavicular ligament; coracoclavicular ligaments is intact
Type III:	Dislocation of the acromioclavicular joint with injury to both acromioclavicular and coracoclavicular ligaments
Type IV:	Dislocation of the acromioclavicular joint with injury to both acromioclavicular and coracoclavicular ligaments. Clavicle is displaced posteriorly through the trapezius muscle
Type V:	Gross disparity between the acromion and clavicle, which displaces superiorly
Type VI:	Dislocated lateral end of the clavicle lies inferior to the coracoid

clavicle are recognized. A neurovascular exam of the involved extremity is important and reducibility of the joint with upward pressure of the elbow stabilizing the clavicle superiorly can be performed (note that the shoulder drops down, the clavicle does not move up).

Using X-rays, a.p. projection of the glenohumeral joint as well as Y-view or transaxillary views are taken. To evaluate the acromioclavicular joint directly, the Zanca view should be used by tilting the center-beam 30–45° caudocranial, aiming on the acromioclavicular joint (Zanca 1971). The Alexander view (Y-view with maximum arm adduction) helps to verify subluxation in acromioclavicular joints (Alexander 1954). If a full dislocation is suspected, a.p. projections comparing both sides should be taken, using 5–10 kg weights. Transaxillary views are highly recommended to diagnose a horizontal instability. Ultrasound offers a good diagnostic tool for degenerative changes as well as lower grade injuries of the acromioclavicular joint (Rockwood I–II). In higher-grade lesions (Rockwood IV–VI), muscle hematoma and ruptured muscle insertions can be diagnosed. The distance from the coracoid process to the clavicle can be measured and compared to the healthy contralateral side. The results correlate positively with X-ray findings [10, 11]. CT scan and scintigraphy (arthritis) can be performed but are of lesser importance than an MRI. Early osteolysis (repetitive trauma) or rheumatoid arthritis can be diagnosed through MRI. In acute acromioclavicular dislocations, a huge number of missed injuries (15 % SLAP lesion, 5 % fractures, 4 % rotator cuff tears) were found [12]. Acromioclavicular separations are classified by Tossy (1963) and Rockwood (1984). Kraus et al. published a new measurement tool for instability of the acromioclavicular joint, the acromioclavicular joint instability score (ACJI), in 2010.

4.5 Treatment

Treatment strategies vary and controversy remains regarding the optimal course of action. There are more than 150 different conservative and operative treatment options to stabilize the joint [2]. There is little literature about long-term results, even for well-established treatment strategies. Likewise, no long-term results for newly developed operative procedures are available [3–7]. At this point, there is no therapeutic gold standard for acromioclavicular joint dislocation. Typically, a surgical indication is made with higher-grade acromioclavicular separations. Rockwood III grade injuries must be evaluated individually.

4.5.1 Conservative Treatment

There is a broad consensus for nonoperative treatment of Rockwood type I and type II lesions. The most accepted method of conservative treatment is a brief period of immobilization in a sling to support the weight of the upper extremity and to limit the stress on the joints ligament. This period of immobilization is accompanied by ice and oral analgesic medication. The patient is encouraged to initiate range of motion activities within the first week of injury to reduce pain and inflammation in an effort to decrease associated morbidity. Strengthening exercises with a specific focus on scapular stabilization follow.

4.5.2 Operative Treatment

After indication for operative treatment (type IV, V, and VI) is made, ruptured ligaments that are unable to be reconstructed need to be removed. Also, the interarticular disc needs inspection. The clavicle must be repositioned and fixation must be performed. Good alignment needs to be achieved and ligaments are thought to heal by scarring. If muscle fascia insertions are partially or completely ruptured, surgical intervention is necessary. Furthermore, other damaged anatomical structures must be addressed. Regarding

Fig. 4.1 Arm position

horizontal stability, surgical treatment of ruptured muscle fascia insertions is of the highest importance.

4.5.2.1 Positioning

The patient is positioned in beach-chair position. The surgeon should check that no material will interfere with fluoroscopy. Frequently, the patient is positioned towards the injured side and the operating table is tilted towards the contralateral side to avoid the patient sliding down off the table. The arm is laid onto a splint and the elbow hangs freely (Fig. 4.1). The ventral and dorsal shoulder aspect as well as the sternoclavicular joint are cleaned and prepared for operation. The arm is freely movable and covered up to the biceps muscle.

4.5.2.2 Procedures

Regarding the anatomy, there are different options available. Bridging the acromioclavicular joint is possible; techniques that address the coracoid process are also available. Combinations of these options are possible as well.

Transarticular K-Wire Fixation

This technique was first described by Murray and Phemister. Using either a frontolateral approach parallel to the clavicle or a saber-type incision, preparation of the coracoclavicular and acromioclavicular ligaments as well as muscle insertions are possible. The insertion point for the K-wires can be set up. After reconstruction or resection of the ligaments and inspection and debridement of the discus has been performed, the clavicle is repositioned. The result is controlled by fluoroscopy before two K-wires (2 mm diameter) are drilled in from the lateral aspect of the acromion, aiming toward the cranial corticalis of the clavicle. Both wires should be positioned in parallel (Fig. 4.2a). Some authors prefer to use just one K-wire to reduce damage to the cartilage. It must be clearly stated that rotation stability is not achieved, which increases the risk of material loosening or even breakage.

In addition to K-wires a metal cerclage can be used. This helps to achieve an even greater stability, and the width of the acromioclavicular joint can also be adjusted. A certain risk of cartilage damage and later degenerative changes is created when compression of the joint participants is too high. The operation ends by adapting the initially prepared sutures of the ligaments and/or suturing the muscle fascia insertions if ruptured. The above-described technique is also used in lateral clavicular fractures, when the fracture zone is seen very laterally. K-wires are also an option in coracoid process fractures (Fig. 4.2b) when the process cannot be used for acromioclavicular stabilization (TightRope, band augmentation). The most striking argument not to use the above-mentioned implants is the need of a second operation for implant removal. Also, partial loss of the reduction result may occur (Fig. 4.2c).

Hook Plates

In case of a fracture zone that is positioned in the area of the coracoclavicular ligaments or even more medially, K-wires should not be used. The clavicular shape inhibits the positioning of the wires and healing will not be achieved. Here we use hook plates, which are not used in cases of isolated acromioclavicular dislocation. Even though modern hook plates (e.g., Dreithaler) seem not to have the disadvantages of earlier implants, the long-term results are not convincing.

TightRope System

The TightRope system (Arthrex, Naples/USA) offers another technique to stabilize the acromioclavicular joint. Compared with other established procedures, it was shown that comparable repositioning results were achieved. Significant advantages for either of the procedures were not shown [13]. Although the

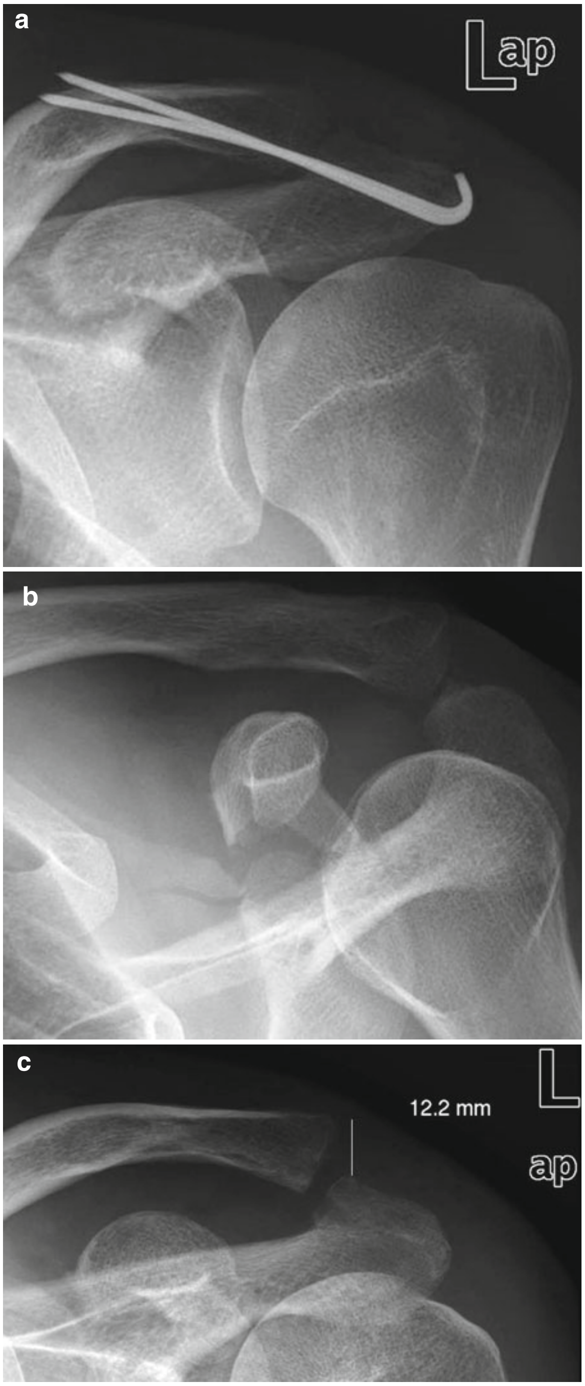

Fig. 4.2 (**a**) Postoperative result. (**b**) Fracture of the coracoid process (oblique view). (**c**) Follow-up after metal removal (week 6), partial loss of reduction result is seen

operative procedure can be assisted arthroscopically, we prefer a minimally invasive approach to the craniodorsal aspect of the clavicle and the ventral margin

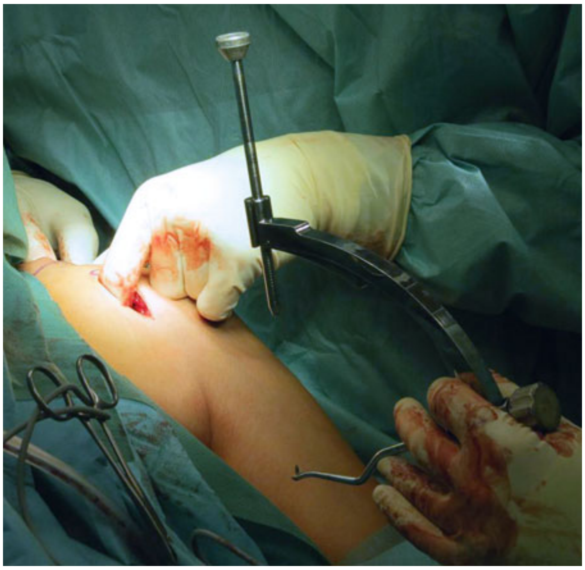

Fig. 4.3 Positioning of the aiming device

of the coracoid process. By using these incisions, muscle damage or ruptured muscle fascia insertions can be addressed. The biceps tendon is incised longitudinally and the tip of the coracoid process can be touched. After preparation, the caudal part of the aiming device is now positioned underneath the coracoid process, while cranially it is positioned on the craniodorsal aspect of the clavicle (Fig. 4.3). A K-wire is drilled towards the clavicle. The first drill hole should touch the insertion of the conoid ligament, which is centrally located on the base of the coracoid process. The position is controlled and overdrilled (diameter 4 mm). The tip of the wire should be protected to avoid descensus and damage by perforation through a moving K-wire (Fig. 4.4). A guiding suture is now brought in through the cannulated drill (Fig. 4.5). The drill is removed afterwards and the aiming device can be set to perform another drill hole that follows the trapezoid ligament and should perforate the coracoid process where the ligament inserts. It is not clear whether it makes sense to have the clavicular holes drilled in parallel or V-shaped. Kraus et al. showed that both procedures are associated with good to very good results [14]. The TightRope itself is next pulled through using the guiding sutures (Fig. 4.6). The endobutton now goes into reverse position underneath the caudal aspect of the coracoid process (Fig. 4.7) and the fixation button can be positioned above the clavicle (Fig. 4.8). Repositioning is performed and controlled via fluoroscopy (Fig. 4.9). When good alignment is achieved, the fixation button above the clavicle is pulled downwards and knots are set. The button needs to touch the clavicle (Figs. 4.8 and 4.12). The ends of the cut sutures must not irritate the covering soft tissue. This may impair wound healing. Alternatively sutures can be guided ventral to the clavicle and around the TightRope itself before another knot is set. In our department, we frequently change the direction in which the TightRope is brought in. Especially in thin people with less soft tissue above the clavicle, the TightRope is brought in caudally. This way the small endobuttons are positioned onto the clavicle (Fig. 4.10) and the fixation button is positioned underneath the coracoid process. Using a knotting aid, fixation of the endobutton is easily achieved (Fig. 4.11). Soft tissue irritation is minimized. The operation ends by careful primary wound closure.

Fig. 4.4 Overdrilling the K-wire and protection of the K-wire's tip

4.6 Acromioclavicular Joint Arthritis

4.6.1 Conservative Treatment

Degenerative changes in the acromioclavicular joint may have different causes. Former injuries to the joint are one possibility. Typically, conservative treatment is preferred but operative techniques are available as well to solve persistent problems.

4.6.2 Operative Technique

4.6.2.1 Open Lateral Clavicular Resection

Gurd and Mumford described an open resection technique in 1941. After the joint capsule is incised, the joint is prepared and the lateral clavicle is resected using an oscillating saw. The interarticular disc is

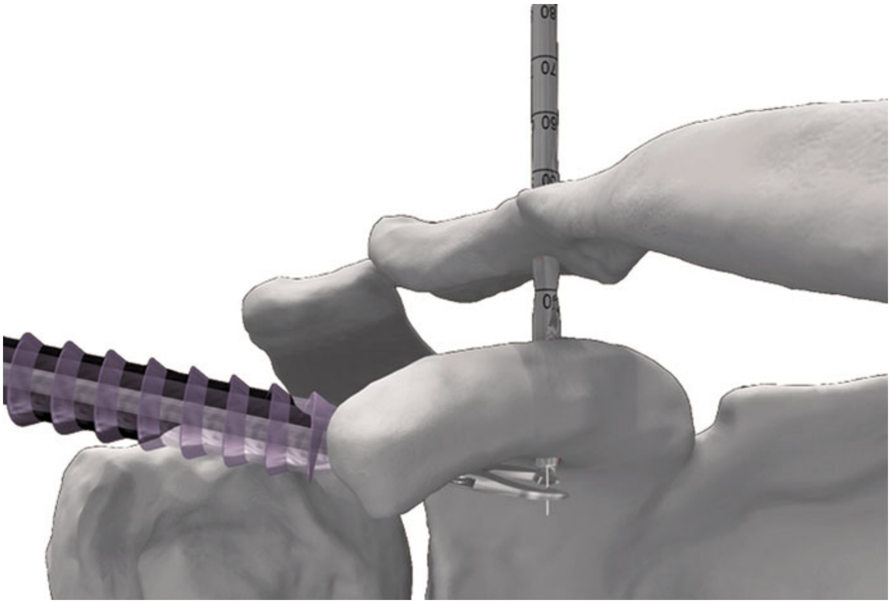

Fig. 4.5 Pulling the guiding suture through the drill (By kind permission of the publisher Arthrex, Naples/USA)

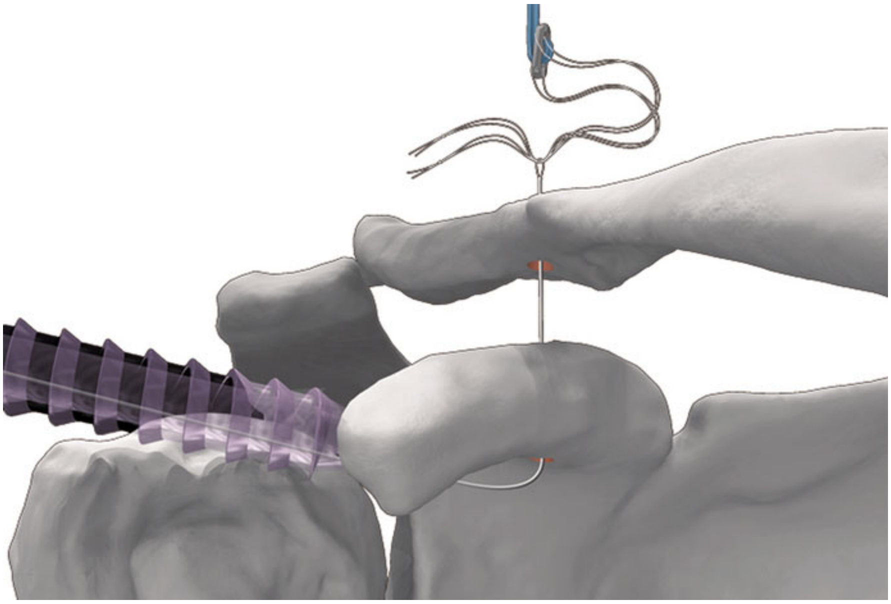

Fig. 4.6 Pulling the TightRope through the holes (By kind permission of the publisher Arthrex, Naples/USA)

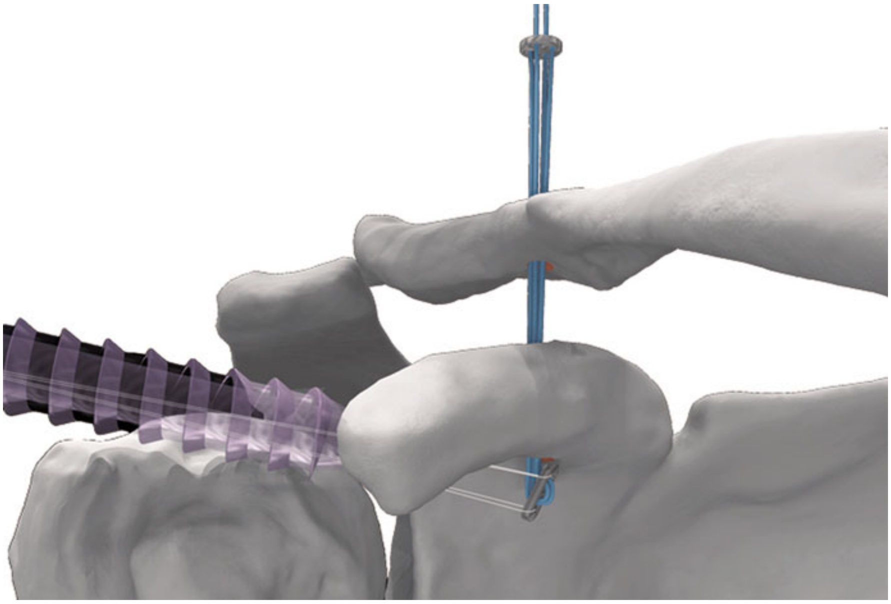

Fig. 4.7 The endobutton flips into reverse position underneath the coracoid process (By kind permission of the publisher Arthrex, Naples/USA)

removed. Literature about the correct resection length varies. There is information about lengths of 2.5 cm to 1.8 cm to 1 cm. Resection lengths over 1 cm seem to be associated with a worse outcome. The reason seems to reside in the acromioclavicular ligaments. Their insertions are affected when the resection length is larger than 1 cm, which decreases their function [15, 16].

4.6.2.2 Arthroscopic Lateral Clavicular Resection

Resection of the lateral clavicle can also be achieved arthroscopically using a shaver. A side effect of this technique is that the ligaments are partially resected. Furthermore, intraarticular joint resection is possible using a mini shaver. This is a demanding technique that is associated with a high technical effort, special instruments,

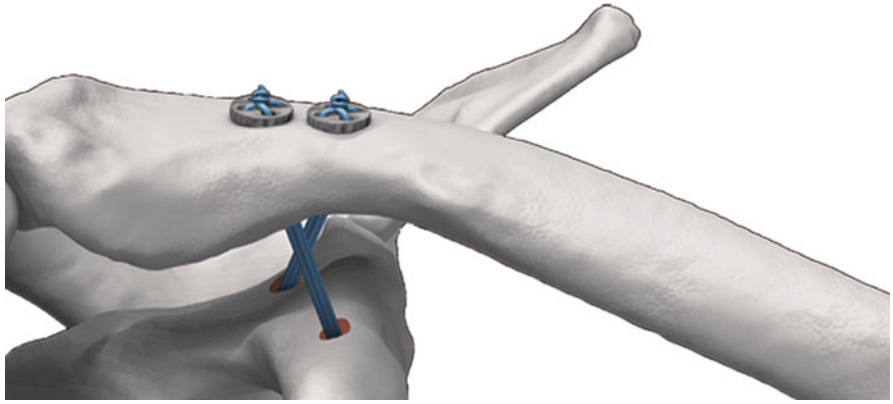

Fig. 4.8 The fixation buttons lay onto the clavicle (By kind permission of the publisher Arthrex, Naples/USA)

Fig. 4.9 Intraoperative radiographic control

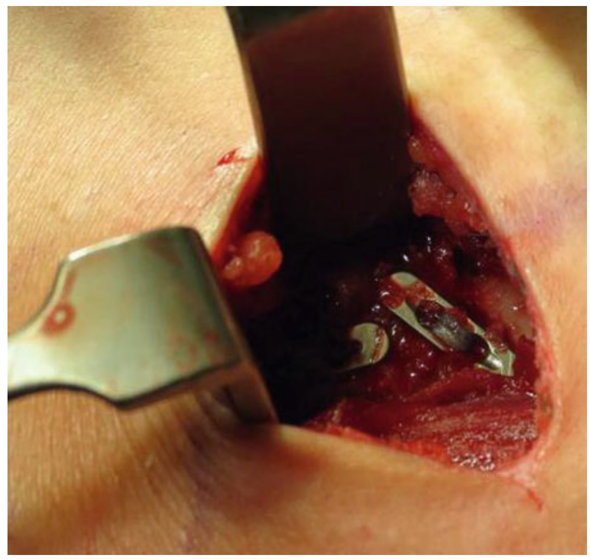

Fig. 4.10 The reversed endobuttons above the clavicle

and increased costs and may be too challenging for an inexperienced surgeon. Postoperatively, the joint components should not have contact, in order to avoid a painful decreased range of motion. It is highly important not to damage the coracoclavicular ligaments. A ligament reconstruction is difficult.

4.6.2.3 Weaver and Dunn Procedure

Weaver and Dunn [19] modified the above-mentioned technique. The coracoacromial ligament is removed from the caudal aspect of the coracoid process and positioned toward the remaining end of the resected clavicle. Transossary fixation is performed. Technically, this procedure is easy and treatment of side injuries in this area is possible. The described procedure is not an adequate treatment option in older acromioclavicular joint separation with a large vertical instability. Also, horizontal stability is not achieved with a Weaver-Dunn technique. Additional band augmentation is necessary and, in case of horizontal instability, a reconstruction of the initial anatomy is of the highest importance. The first biomechanical results using autologous ligament reconstruction techniques seem to be promising [17, 18]. The anatomical situation has changed in patients who have undergone prior surgery of the shoulder (e.g., a Weaver-Dunn operation) and therefore the experienced surgeon must question doing any kind of revision surgery. These operations must be planned carefully; the area where ligaments are taken from needs to be thoughtfully chosen and follow-up treatment is predicated on good compliance.

Fig. 4.11 Reposition maneuver and TightRope fixation

Table 4.2 Follow-up treatment

Postoperative week	K-wire	Tightrope
1–2	Passive Internal/external rotation 90-0-0 Abduction/flexion max. 30°	
3–4	Active-assisted Internal/external rotation 90-0-0 Abduction max. 70° Flexion max. 90°	Active-assisted Internal/external rotation 90-0-0 Abduction/flexion max. 45°
5–6	Active Internal/external rotation free Abduction/flexion max. 60°	
7–8	Removal of K-wires	Free range
12–16	Full weight bearing	
16–24	Training phase for professional athletes, full weight bearing	

4.7 Follow-Up Treatment

The patient receives a Gilchrist bandage. We recommend the bandage for up to 3 weeks. If weight is brought onto the operated area too early, this may result in impaired healing of repaired muscle fascia insertions. Passive-assisted physiotherapy is possible after the first postoperative week. Flexion and abduction is limited to 30°. External rotation should be strictly avoided. With the third postoperative week the patient can start active-assisted training. Flexion and abduction is limited to 45° and external rotation should be avoided until the end of the fourth postoperative week. If K-wires are used, the limitation in flexion and abduction should be 90° to avoid any material breakage. External rotation is possible the beginning of the fifth postoperative week when using TightRopes. Flexion and abduction to 60° is then possible and full range of motion is possible from the seventh postoperative week on. The K-wires should be removed by this time and any restrictions in range of motion be revoked. The patient is allowed full weight bearing 3–4 months after the operation (Table 4.2). Radiographic control can be performed (Fig. 4.12).

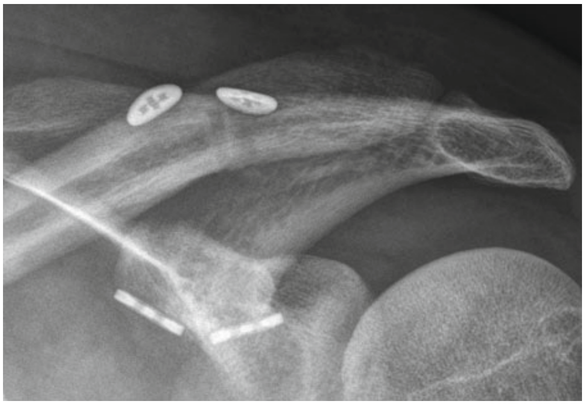

Fig. 4.12 Long-term result (>4 months)

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Clavicle Fractures

5

Hans-Jörg Oestern

5.1 Anatomy

Morphologically, the clavicle is a subcutaneous, S-shaped long bone with an anterior apex medially and posterior apex laterally. The sternocleidomastoid, attached to the medial third, provides the major deforming force on the medial fragment, pulling superomedially in a midshaft fracture. The pectoralis maior and the weight of the arm provide the maior deforming force on the lateral fragment, pulling inferomedially and anteriorly in fractures of the middle third [4]. Overlying the clavicle and its attached muscles are the branches of the supraclavicular nerves and the platysma muscle. During a surgical exposure of the clavicle, the platysma must be divided. Just deep to it are the supraclavicular nerves branches over the medial and middle thirds of the clavicle.

5.2 Biomechanics

Functionally, the clavicle acts as a strut that connects the shoulder girdle to the axial skeleton. Clinical and biomechanical studies demonstrate the importance of restoring and maintaining the normal length of this strut, and hence the attached muscle unit length, to optimize the functional recovery of the shoulder girdle following a clavicle fracture [1, 2].

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5.3 Epidemiology

Clavicle fractures represent up to 5 % of all adult fractures and up to 44 % of all shoulder girdle fractures. The overall incidence of the injury was estimated to be between 29 and 64 per 100,000 population per year.

5.4 Classification

The most widely used classification divided the clavicle into three equal segments, fractures of the medial third, middle third, and lateral third.

With respect to the incidence of different fracture types, fractures of the middle third of the clavicle are by far the most common, accounting for 69–81 % of all clavicle fractures. The second most common type is fracture of the lateral or distal third of the clavicle, accounting for 16–30 % of all clavicle fractures. Less than 3 % of all clavicle fractures are fractures of the medial or proximal third of the clavicle [3].

5.5 Mechanism of Injury

Most clavicle fractures result from a fall or from a direct blow to the shoulder. This compressive force onto the clavicle is estimated to account for more than 85 % of all clavicle fractures. The middle third of the clavicle is the thinnest segment of the bone and is devoid of any protective muscular or ligamentous attachment, rendering it the weakest point of the bone. Therefore, clavicle fractures most commonly involve the middle third of the clavicle [4, 5].

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5.6 Clinical Evaluation

On physical examination, inspection of the injured clavicle often reveals a tender, bony protuberance under the skin, ecchymosis, and swelling at the fracture site. Prolonged skin tenting may lead to skin necrosis and a secondarily open fracture. The ipsilateral shoulder may demonstrate a typical droop or ptosis with associated scapular anterior rotation or winging and a shortened clavicle. A sizable and/or expanding hematoma around the fracture site may indicate an injury to the subclavian vessels that necessitates an inspection for a local bruit, diminished or absent distal pulses, and asymmetrical blood pressure measurements in the arms. A thorough neurologic examination is mandatory.

5.7 Radiologic Evaluation

For an isolated clavicle injury, routine radiograph starts with a full-length antero-posterior view of the clavicle, which includes the SC and AC joints as well as the shoulder girdle. A 45° cephalic tilt view of the clavicle helps delineate further the degree of displacement and comminution at the fracture site and profiles the clavicle superior to the thorax.

5.8 Treatment

5.8.1 Fractures of the Medial Third of the Clavicle

The major cause of injuries to the medial third of the clavicle is high-energy trauma. These fractures are difficult to visualize on plain radiographs and are best delineated with a CT scan. Associated intrathoracic injuries such as pneumo/hemothorax and lung contusions, as well a head and neck injuries, are found frequently [8].

Particulary in pediatric and adolescent patients, retrosternal SC dislocations or medial epiphyseal separations threatening the neck of the mediastinal contents often have been treated operatively (Fig. 5.1).

5.8.2 Fractures of the Middle Third of the Clavicle

More than 200 different methods of immobilization, bracing, or sling treatments have been devised for the nonoperative treatment of displaced fractures of the clavicle. The number of treatments attests to the extreme difficulty of achieving and maintaining reduction. Recommended periods of immobilization vary from 2 to 6 weeks, individualized to the patient's comfort level. Secondary to the typical displacement of the lateral fragment with inferior and medial translation and anterior rotation, shoulder weakness and easy fatigability and thoracic outlet syndrome have been noted. There exists also an association between significant shortening (>15–20 mm) of the clavicle and symptomatic malunion.

5.8.2.1 Operative Treatment

Indication

Indications are open fractures, impending perforation of the skin, and fractures with associated vascular injury requiring surgical repair, relative indications are severe displacement and shortening.

Primarily, two widely accepted methods of fixation – plate fixation or intramedullary pinning – are used in the operative treatment of fractures of the middle third of the clavicle.

Plate Fixation

The approach is either straight over the clavicle or in the sagittal plane. For minimally invasive surgery, two incisions are made at each end of the plate. After dissection of the platysma the supraclavicular nerves are identified.

For plate fixation, dynamic compression plates, pelvic reconstruction plates, and anatomic precontoured plates have been used. Although their low profile may lead to less skin irritation, semitubular plates and mini-plates were found to be mechanically too weak for rigid fixation and are not recommended. Plate fixation has superior biomechanical strength that offers excellent rotational and length control and allows early weight bearing on the limb. The main disadvantages are the long skin incision and tissue dissection around the fracture, the hardware prominence, which may require plate removal, and possible refracture after the plate removal. As experience with precontoured "anatomic" plates and surgical technique increases, minimally invasive soft tissue handling can result in dramatic decreases in incision size. Intramedullary fixation offers the advantages of being a soft tissue friendly and minimally invasive or percutaneous procedure with the potential for improved cosmesis. The main disadvantages of the method of fixation (common to all "unlocked" intramedullary devices) are its inferior axial and rotational stability

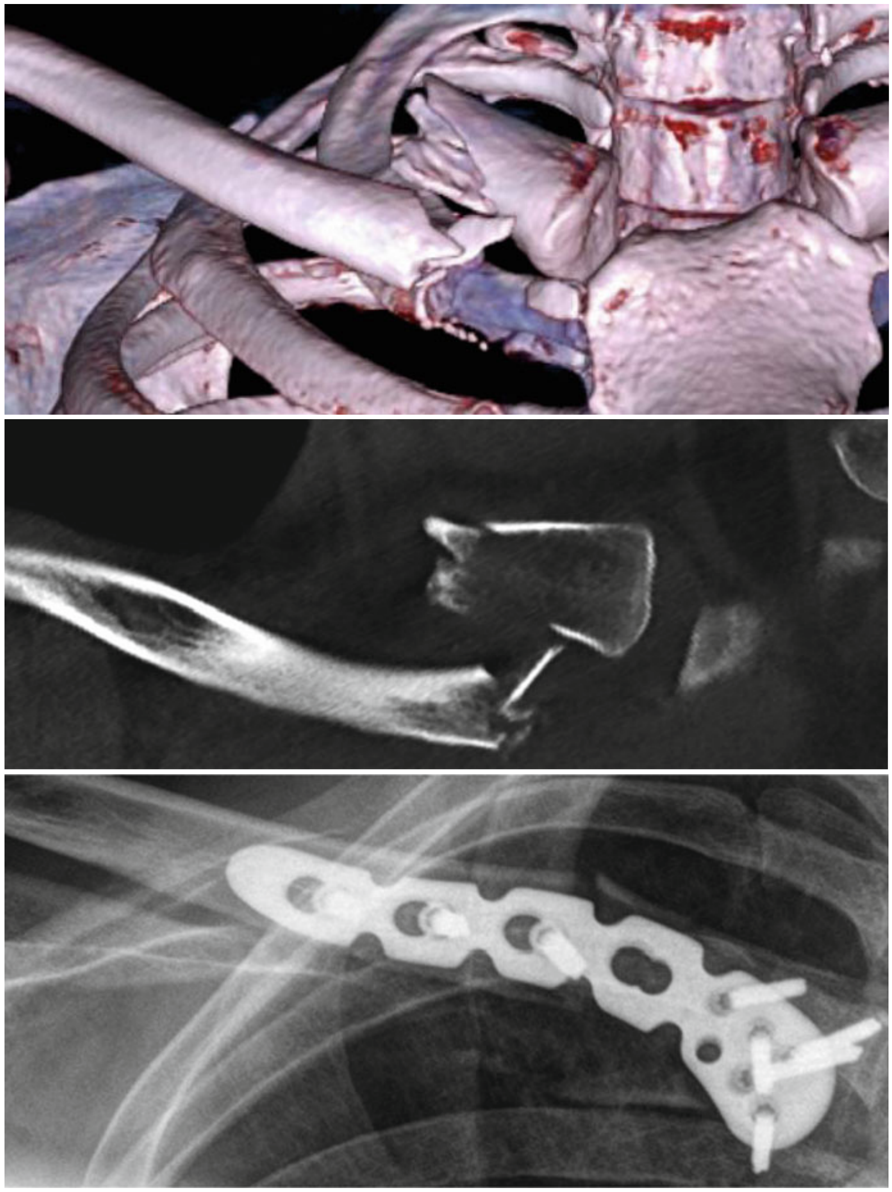

Fig 5.1 Dislocated fracture of the medial clavicle, fixed by special clavicula plate

in nontransverse and comminuted fractures. The plate usually is placed on the superior aspect of the clavicle, because this placement has been shown to be the most advantageous biomechanically. An anterior approach is also possible. Whenever possible, branches of the supraclavicular nerves are identified, mobilized, and protected. A minimum of three bicortical screws are used distal and proximal to the fracture; a lag screw is placed whenever possible. Smaller fracture fragments (including a fairly consistent vertically oriented anterior cortical fragment) are "teased" into position without stripping all their soft tissue (Fig. 5.2).

Elastic Stable Intramedullary Nailing

Intramedullary nailing has the advantage of being a minimally invasive or percutaneous procedure without disturbing the soft tissue. It also offers less pain and faster return to work, better functional results, and less shortening when compared with conservative treatment. The disadvantages are its inferior axial and rotational stability in nontransverse and comminuted fractures; in up to 30–40 % patients the clavicle diameter is too small for a closed procedure or closed reduction is not possible. Then it is necessary to open the fracture site [6, 7].

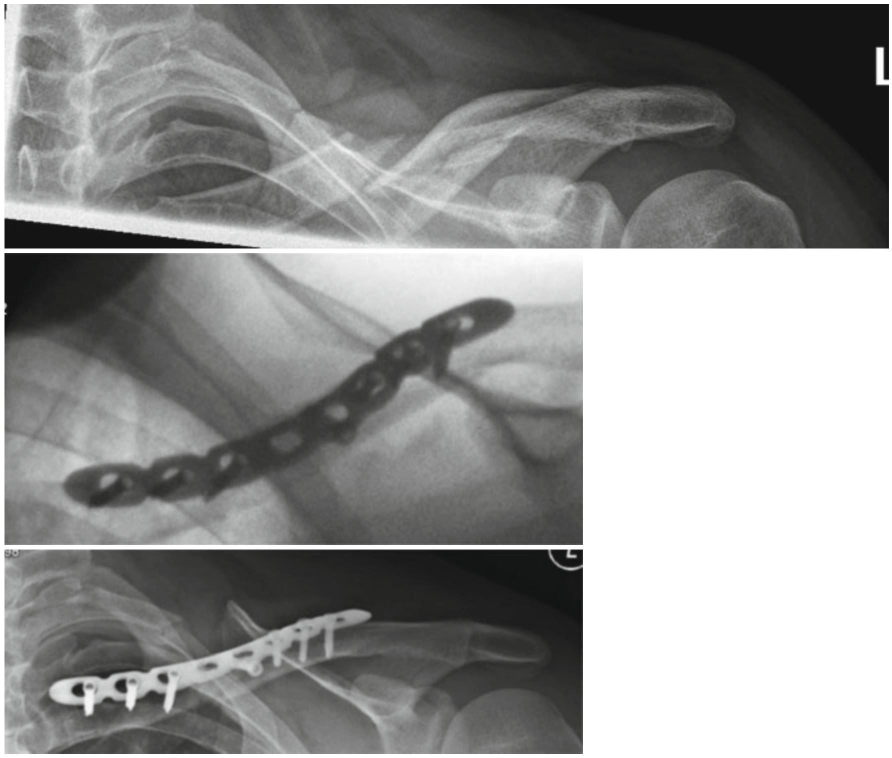

Fig. 5.2 Primary severe dislocated midshaft clavicle fracture fixed by an LCP

Surgical Procedure

The patient is placed on a radiolucent operating table in a supine position. A roll of towels is placed beneath the scapulae to fully extend the clavicle. After clavicle extension, fluoroscopy is used to check for overlap of the fracture site. A small skin incision (1–2 cm) is made 1 cm lateral of the sternoclavicular joint. The anterior cortex is opened with a reamer; 2.5 mm titanium nails in men and 2 mm in females are used. The TEN is fixed in a universal chuck with a T handle. By use of oscillating hand movements, the unreamed TEN is advanced until it reaches the fracture site. Under fluoroscopic monitoring the nail is introduced into the lateral fragment by closed manipulation of the fragment. If closed reduction fails, an accessory incision of 3 to 4 cm is made above the fracture site to enable direct manipulation of the lateral fragments. The end of the nail is cut off, bent, and embedded beneath the soft tissue without violation of the overlying skin [6, 7] (Fig. 5.3).

5.8.3 Fractures of the Lateral Third of the Clavicle

Most fractures of the lateral third of the clavicle (especially fractures that are non- or minimally displaced) can be treated successfully with a period of immobilization.

Given the current paucity of high-level therapeutic evidence regarding these injuries, operative treatment should be individualized and reserved for young, active patients (especially those engaged in throwing or overhead activity) who have completely displaced fractures of the distal clavicle.

If a low-profile "anatomic" plate is used for fixation, the plate first can be fixed provisionally to the medial-clavicle fragment to aid in reduction. Anatomic distal clavicle plates offer extra holes for screws in the cancellous bone of the distal clavicle to enhance distal fixation (Fig. 5.4).

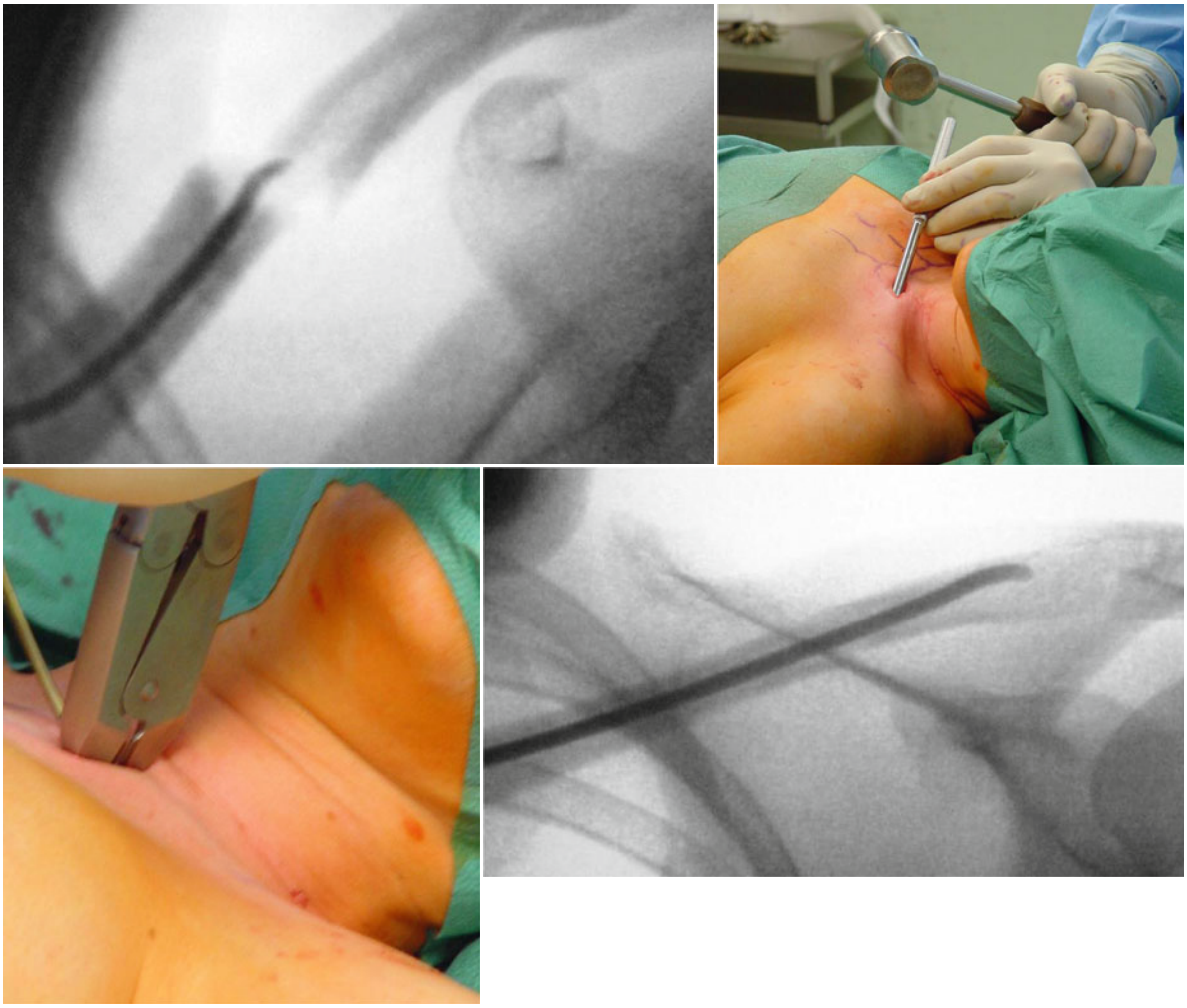

Fig. 5.3 Midshaft transverse fracture. Elastic nail fixation from the medial side

Postoperatively, the arm stays in the sling on a full-time basis for 2 weeks followed by active assistive range-of-motion exercises in the scapular plane of motion.

5.9 Floating Shoulder

Floating shoulder is a rare injury pattern consisting of ipsilateral clavicle and glenoid neck fractures. The concern is that the weight of the arm together with ligament disruptions and the pull of the muscles around the shoulder girdle continue to displace the glenohumeral joint inferiorly as well as anteromedially.

Treatment must be individualized, usually based on the degree of displacement: greater deformity an a higher activity levels are indications for more aggressive primary treatment, either by stabilization of the clavicle and/or the glenoid (Figs. 5.5 and 5.6).

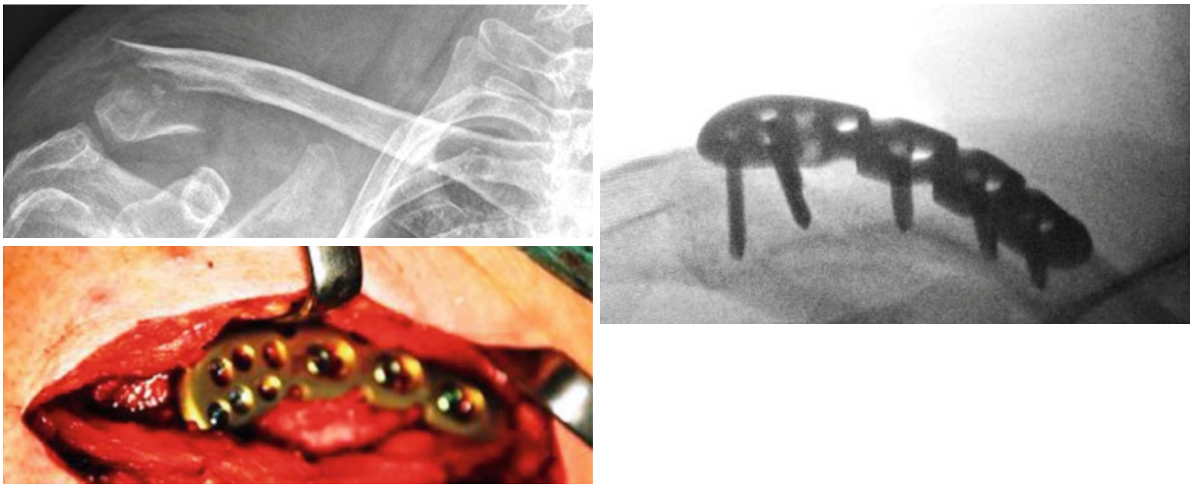

Fig. 5.4 Lateral clavicle fracture fixed by a special clavicle plate

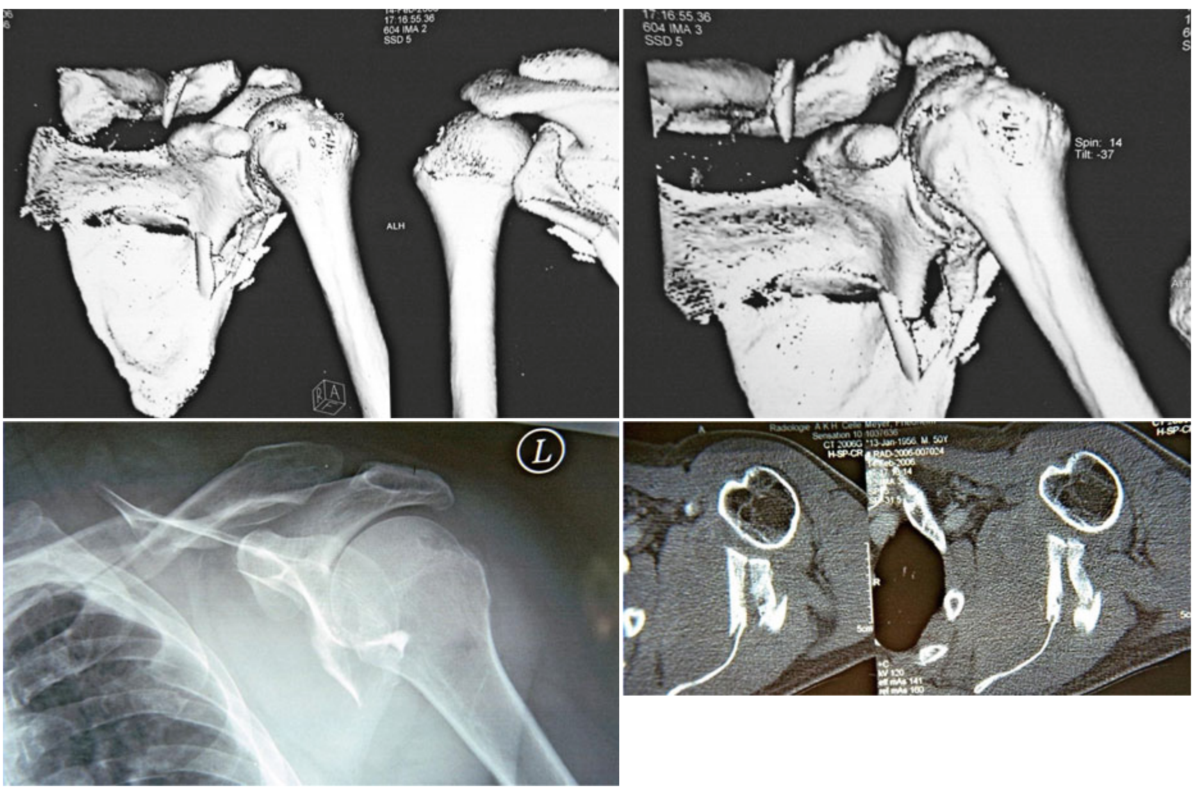

Fig 5.5 Floating shoulder

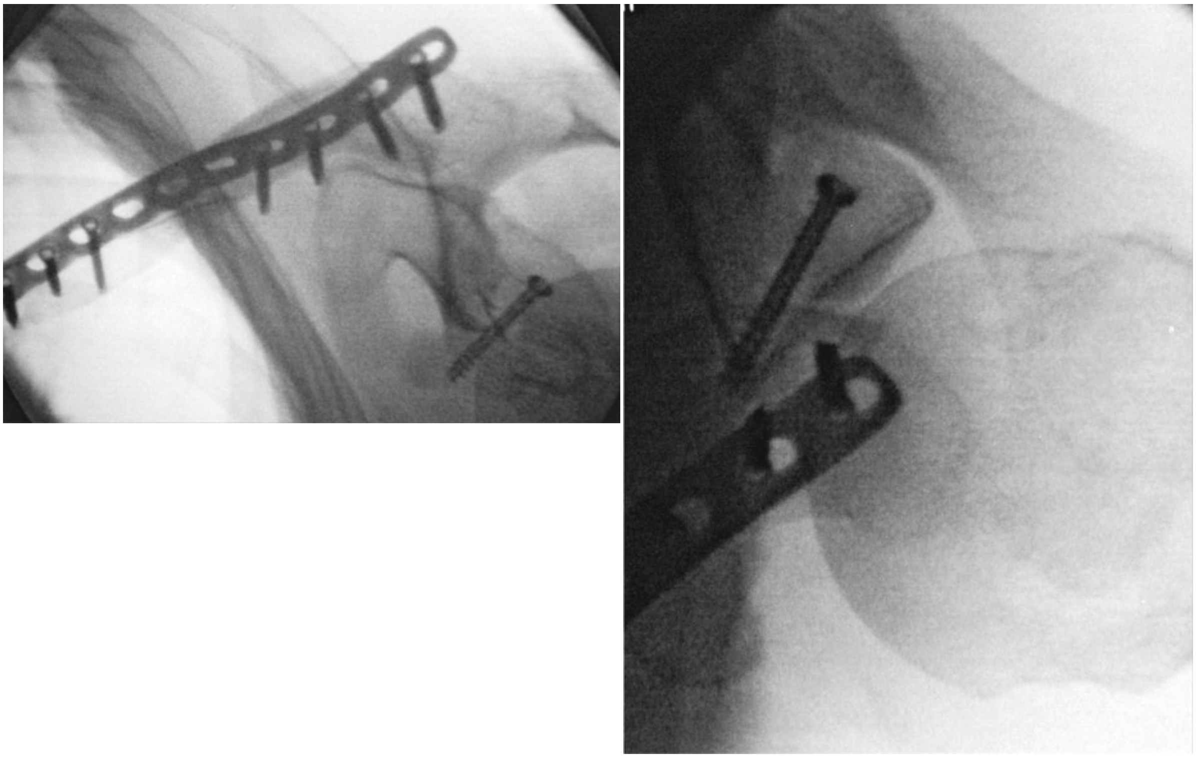

Fig 5.6 Arthroscopic fixation of the displaced glenoid frcture

5.10 Complications of Clavicle Fractures

Complications of clavicle fractures include nonunion in severe displaced conservative treated fractures, vascular injuries (subclavian artery and vein), brachial plexus irritation, weakness in shortening, and thoracic outlet syndrome.

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Scapula Fractures

6

Jan Friederichs and Volker Bühren

6.1 Epidemiology

Being protected by strong muscles and soft tissue and due to the mobility of surrounding joints, scapular fractures are relatively rare and represent only 0.4–1 % of all fractures and 3–5 % of fractures of the shoulder girdle. The mean age of patients with fractures of the scapula is reported to be between 25 and 42 years, and the majority of patients are male. Scapular injuries occur mainly in the setting of high-energy trauma. Direct blunt force is most often responsible for fractures of the body of the scapula, whereas indirect trauma causes fractures of the glenoid, process fractures, or fractures of the scapular neck. Maximal indirect traction mechanism through the ipsilateral arm might lead to a scapulothoracic dissociation with an internal forequarter amputation of the arm involving vascular and plexus structures.

In Europe, road traffic accidents account for approximately 50 % of scapular fractures, followed by motorcycle accidents (25 %) and accidents involving bicycles, pedestrians, and falls from heights. Scapular fractures are a strong indicator for high-energy trauma and concomitant injuries should be expected. Up to 90 % of concomitant injuries are reported in literature, thoracic injuries in 80 %, injuries of the ipsilateral upper extremity in 50 %, associated head injuries in 48 %, and spinal fractures in 26 %. The rate of polytraumatized patients in our own study collective reached 40 %; only 15 % of patients suffered of a scapular fracture without a concomitant injury. Because the focus is on life-threatening concomitant injuries, the diagnosis of a scapular fracture is often missed or delayed and the treatment postponed. However, in 1579, Amroise Paré stated that "when a fracture involves the neck of the scapula, the prognosis is almost always fatal"[1, 2].

6.2 Anatomy

A thorough knowledge of the scapular anatomy is required to understand complex fractures of the scapula and injuries of the shoulder girdle. Especially for the planning of a surgical procedure, the knowledge of osseous structures (body, neck, spine, coracoid process, and acromion), muscle attachments and tendons, vascular structures, and adjacent nerves (N. suprascapularis, N. axillaris, Plexus brachialis) is absolutely mandatory. Different surgical approaches, depending on the fracture pattern, have been described and a repertoire of incisions, access routes, and muscular intervals are of great importance for successful surgery.

For a better understanding of complex shoulder injuries, such as simultaneous fractures of the scapula and the ipsilateral clavicula, process fractures, or ligamentous injuries, the Superior Suspensory Shoulder Complex (SSSC) was described by Goss and coworkers in 1993 [3]. In this model, the stability of the

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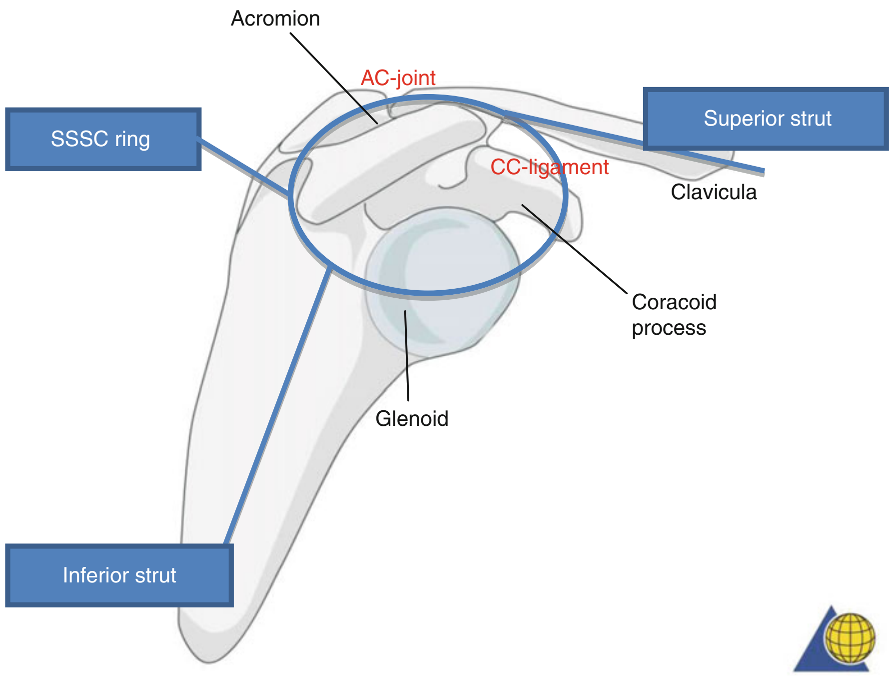

Fig. 6.1 The Superior Suspensory Shoulder Complex (SSSC) according to the description of Goss, 1993. Osseous structures of the SSSC ring are marked in *black*, the ligamenteous structures in *red*

shoulder girdle depends on two struts and a ring structure. The superior strut consists of the middle clavicle, the scapular body and spine make up the inferior strut. As shown in Fig. 6.1, the ring is made up by the lateral clavicle, the acromioclavicular joint, the acromion, the acromiocoracoid and the coracoclavicular ligaments, and the coracoid process [4]. A simple disruption of the ring does not cause an instability, whereas a double lesion is associated with an unstable shoulder girdle. Although this theory is supported by cadaver studies [4], there is still confusion about the correct use of the term "floating shoulder."

6.3 Clinical and Radiologic Evaluation

History and the mechanism of the injury are helpful to identify scapula fractures and concomitant injuries. The physical examination is mandatory; it may reveal skin abrasions, lacerations, ecchymosis, swelling, or a flattened appearance of the shoulder girdle. The patient will complain about pain and motion will be reduced. However, sometimes the symptoms are unspecific or underscored by severe injuries of head, thorax, or spine so that scapular fractures are primarily missed or not adequately treated as the focus is on other life-threatening injuries. As concomitant vascular injuries or damage of neural structures (plexus) are common and greatly influence the overall outcome, a detailed neurologic examination and evaluation of the vascular status are part of the primary physical examination.

A radiographic examination based on a standard series of three projections (true a.p., axillary, and y-view) should be obtained for the diagnosis of a displaced scapular fracture. However, if the fracture shows a strong displacement and a surgical intervention is planned, the gold standard is three-dimensional computed tomography. The 3D reconstruction can be rotated into optimal planes for a comprehension of complex scapular injuries and for an accurate measurement of displacement, especially when the glenoid or the scapular neck are involved. Because computed tomography is easily available, scans are quick, and complete trauma scans are performed on most of the patients with severe thoracic trauma, conventional radiographic workups are not recommended as a standard diagnostic tool for scapular fractures. In case of concomitant injuries such as vascular damage or a neurologic deficit, the diagnostic methods have to be expanded and an MRI or angiographic examination must be added (Fig. 6.2).

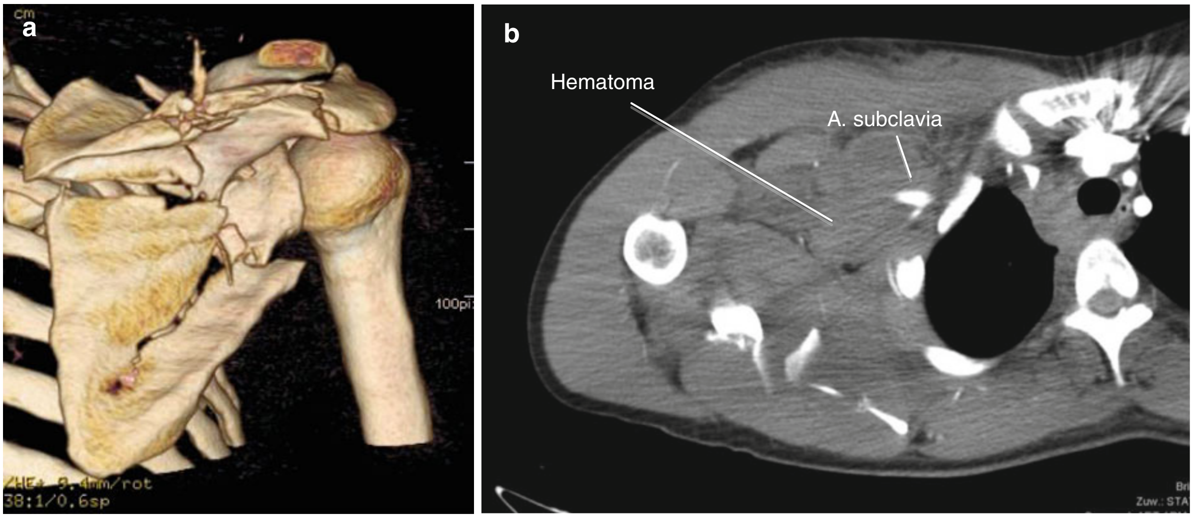

Fig. 6.2 Three-dimensional reconstruction of the computed tomography of a dislocated and unstable fracture of the scapula (**a**) as the gold standard in the diagnosis of scapular fractures. In case of concomitant vascular injuries, angiographic imaging should be added, demonstrating a ruptured subclavian artery with the surrounding hematoma (**b**)

6.4 Classification

Scapular fractures can be classified as extraarticular or intraarticular fractures, body-, neck-, or glenoid-fractures, displaced or nondisplaced fractures, and injuries with a stable or an unstable shoulder girdle. However, for clinical use and for scientific workup, a more sophisticated classification is necessary. In Europe, the classification described by Euler and Rüedi is commonly used and practicable [5]. Three subgroups describe extraarticular fractures (Type A: scapular body fractures, Type B: fracture of scapular process, Type C: fractures of the scapular neck), Type D fractures describe intraarticular fractures, and scapular fractures in combination with fractures of the humerus are classified as Type E. The complete Euler and Ruedi classification is shown in Table 6.1.

Fractures of the glenoid (intraarticular fractures, Type D) are subdivided according to the classification of glenoid rim and fossa fractures described by Ideberg [6] in 1995: Type I–fractures of the glenoid rim, Type IA anterior and Type IB posterior; Type II–transverse fractures through the glenoid fossa with an inferior fragment; Type III–transverse fracture exiting in the mid-superior scapula; Type IV–transverse fracture extending to the medial scapular border; Types V and VI–fracture with extension of a secondary fracture line to the lateral scapular border.

Table 6.1 Classification of scapula fractures according to Euler und Rüedi (1993) [5]

A		Fractures of the scapular body
B		Isolated process fractures
	B1	Spine
	B2	Coracoid process
	B3	Acromion
C		Fractures of the collum
	C1	Collum anatomicum
	C2	Collum chirurgicum
	C3	Collum chirurgicum and
		(a) clavicula fracture
		(b) ruptured coracoclav. and coracoacrom. Ligaments
D		Intra-articular glenoid fractures
	D1	Fractures of the glenoid rim
	D2	Fractures of the fossa glenoidalis
		(a) with inferior glenoid fragment
		(b) transverse fractures through glenoid
		(c) separate coraco-glenoid fragment
		(d) fracture with multiple fragments
	D3	Intraarticular glenoid fractures in combination with fractures of the collum or corpus
E		Fractures of the scapula in combination with proximal fractures of the humerus

Complex shoulder injuries, often referred to as double lesions of the superior suspensory shoulder complex or "floating shoulders," represent a special entity of scapular fractures. In most cases, these unstable shoulder girdle injuries are caused by the combination of a fracture of the scapular neck with a fracture of the ipsilateral clavicle or a lesion of the ipsilateral acromioclavicular joint. However, there are other injury patterns that can result in an unstable shoulder girdle, and a classification has not been described yet.

6.5 Nonsurgical Treatment

Many different publications and authors suggested criteria for surgical and nonsurgical treatment of scapula fractures, such as displacement, stability, medialization, angulation, or shortening [1, 7]. Although definitive proof of the benefit of surgical intervention is lacking for most fracture types, contemporary opinion defines two indications for surgery, displacement and instability. Stable, undisplaced, or minimally displaced fractures of the scapula should be managed conservatively.

Conservative treatment consists of immobilization in a Gilchrist bandage or a sling for approximately two weeks until the fracture starts consolidation and pain subsides. Pain medication, treatment of concomitant injuries, and physiotherapy are mandatory in this period. After 2 weeks and a radiographic control for secondary displacement, progressive passive movement is allowed, and techniques should be demonstrated by an experienced physiotherapist. Six weeks after trauma, progressive active range of motion is allowed followed by a strengthening and endurance program for another 4 weeks. A normal, painless range of movement should be reached 3 months after the injury.

During the first period of nonsurgical treatment of scapula fractures, a pseudoparalysis or loss of control of the injured shoulder is often experienced by the patient. Serial radiographs should be obtained in this period to rule out secondary displacement and progressive deformity.

6.6 Surgical Treatment

Indications for surgical treatment can be summarized under the aspect of dislocation and instability. For glenoid fractures, an intraarticular step-off of more than 2 mm is generally seen as an indication for surgery (Fig. 6.3a). An isolated fracture of a scapular process as the coracoid or the acromion should be treated surgically if a displacement of more than 5 mm is apparent (Fig. 6.3b) and in case of a painful nonunion, although these recommendations are not based on strong evidence. Indications for surgical treatment of fractures of the scapular body and neck are still controversial. Union can be achieved in almost all stable fractures, however, a better outcome may be achieved in strongly dislocated fractures. For this reason, a medialization or dislocation of more than 10 mm, a glenopolar angle of more than 20°, or an angulation of the scapular body of more than 30° should be considered as an indication of surgical treatment (Fig. 6.4a).

Scapular fractures with concomitant osseous or ligamentous injuries of the ipsilateral shoulder are often referred to as a double lesion of the Superior Shoulder Suspensory Complex, a floating shoulder, or a complex shoulder injury. Thorough diagnostic attention is necessary to understand these complex fracture patterns, determine the stability of the shoulder girdle, and provide the patient with an adequate surgical or conservative therapy. At this point of time, no study provides measurable surgical indications beyond the theory that double lesions of the SSSC are unstable and should be treated surgically. However, Williams and coworkers [8] reported on biomechanical data that not all double lesions are unstable and thus not all fractures of the scapular neck with concomitant fractures of the clavicle have to be treated as floating shoulders. Additionally, there is disagreement whether a reduction and fixation of the clavicula alone has the potential to reduce and stabilize the shoulder girdle or if an open reduction and fixation of both scapula and clavicula is necessary to achieve good results (Fig. 6.4b).

In the opinion of the authors, again, displacement and stability are the key indications for surgery. Displaced complex shoulder injuries should be treated surgically with both scapula and clavicula being addressed, depending on dislocation. For the decision as to whether an injury is stable or not, three-dimensional computed tomography and an anatomic understanding of the injury pattern are mandatory. The role of MRI diagnostics is still unclear, and additional information about the ligamentous structures of the SSSC might be helpful to diagnose nondisplaced but unstable injuries. If the injury is classified as an unstable fracture, an open reduction and internal fixation of

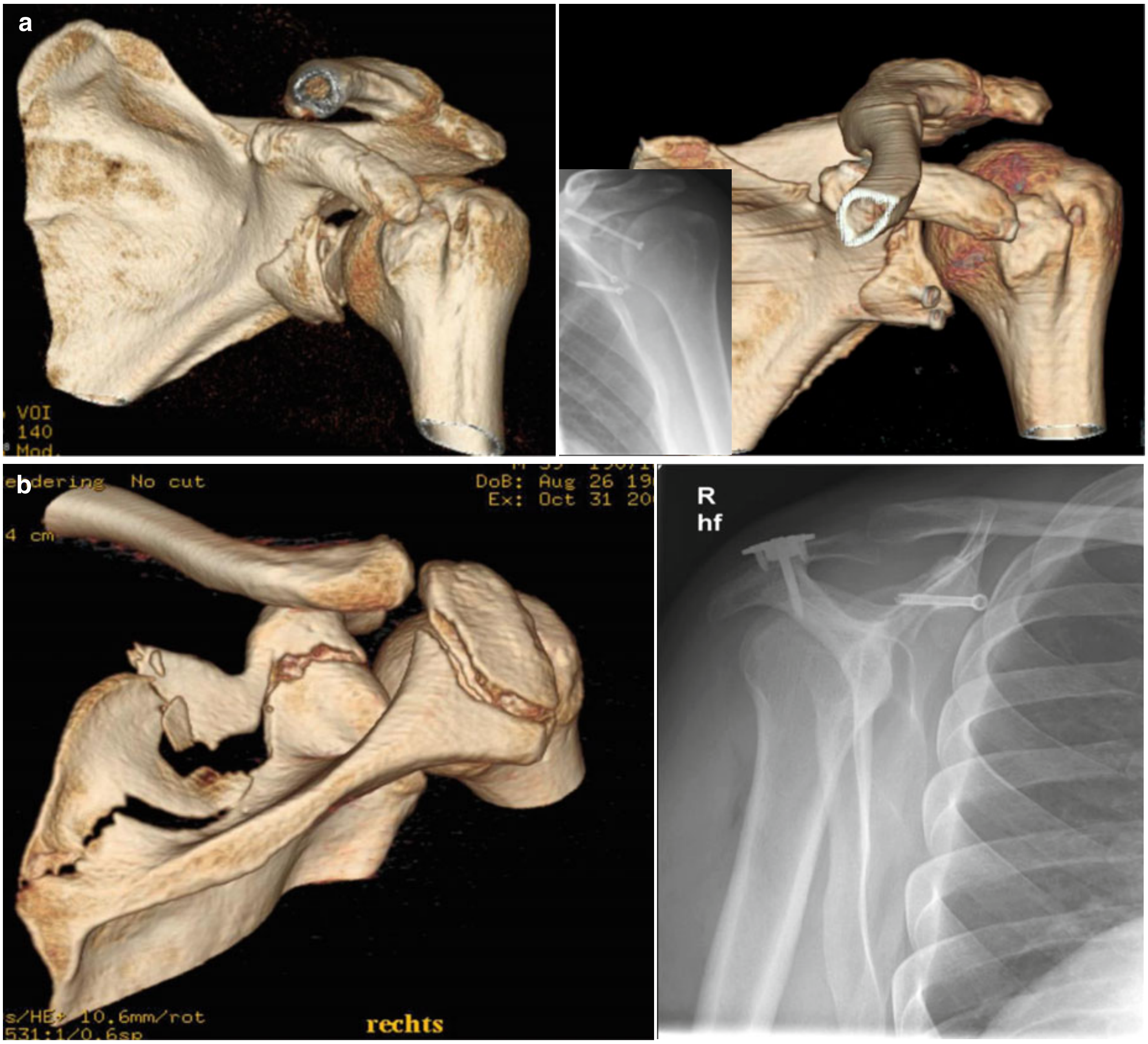

Fig. 6.3 Open reduction an osteosynthesis with three screws of a displaced glenoid fracture. Pre- and postoperative three-dimensional computed tomographies are shown in (**a**) as well as the a.p. postoperative radiographic result. (**b**) A patient with dislocated fractures of the acromion and the coracoid process treated with an open reduction and plate osteosynthesis of the acromion and a closed reduction and osteosynthesis with a cannulated screw of the coracoid process

the scapula is an appropriate treatment; fractures of the acromion, the coracoid, or the clavicle should only be addressed if they are displaced.

6.6.1 Surgical Approaches and Techniques

The correct surgical approach for a specific fracture pattern plays an important role for the overall success. A multitude of approaches and fixation techniques have been proposed, and the commonly used standards will be described in the following paragraph. For special indications, minimally invasive approaches with windows directly over the site (scapular spine, glenoid, coracoid, acromion) can be used, knowing that the possibilities of a correct reduction are limited.

The anterior or deltopectoral approach is the standard incision for glenoid fractures involving the anterior and inferior glenoid. With limited or combined anterior incisions, the coracoid and the acromioclavicular joint can be addressed. Fractures of the posterior glenoid, the scapular neck, or the scapular body

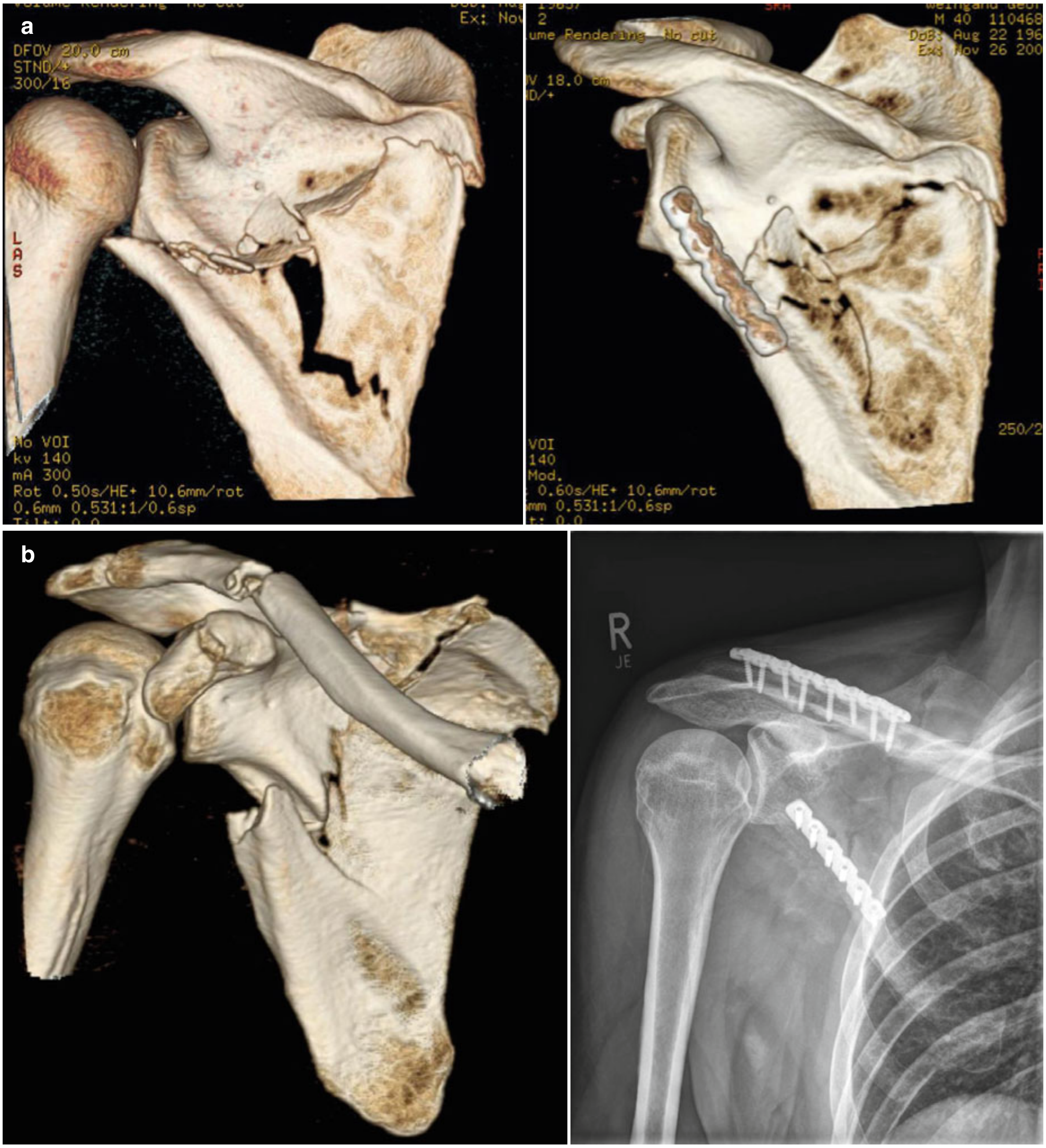

Fig. 6.4 A dislocated fracture of the scapular body can be an indication for an open reduction and osteosynthesis as shown in (**a**). Unstable and dislocated complex injuries of the shoulder girdle ("floating shoulder") are an indication for surgery and the scapula should be addressed via a dorsal approach. As shown in (**b**), the dislocated fracture of the clavicle was also treated by an open reduction and a plate osteosynthesis

make up the majority of scapular fracture patterns and are addressed through a posterior approach. Several posterior incisions have been proposed, one of the first being Judet's approach [9], offering access to almost all regions and borders of the scapula. For complex and unstable injuries of the scapula, the authors suggest using this approach beginning at the acromion and angling down along the vertebral border as far as

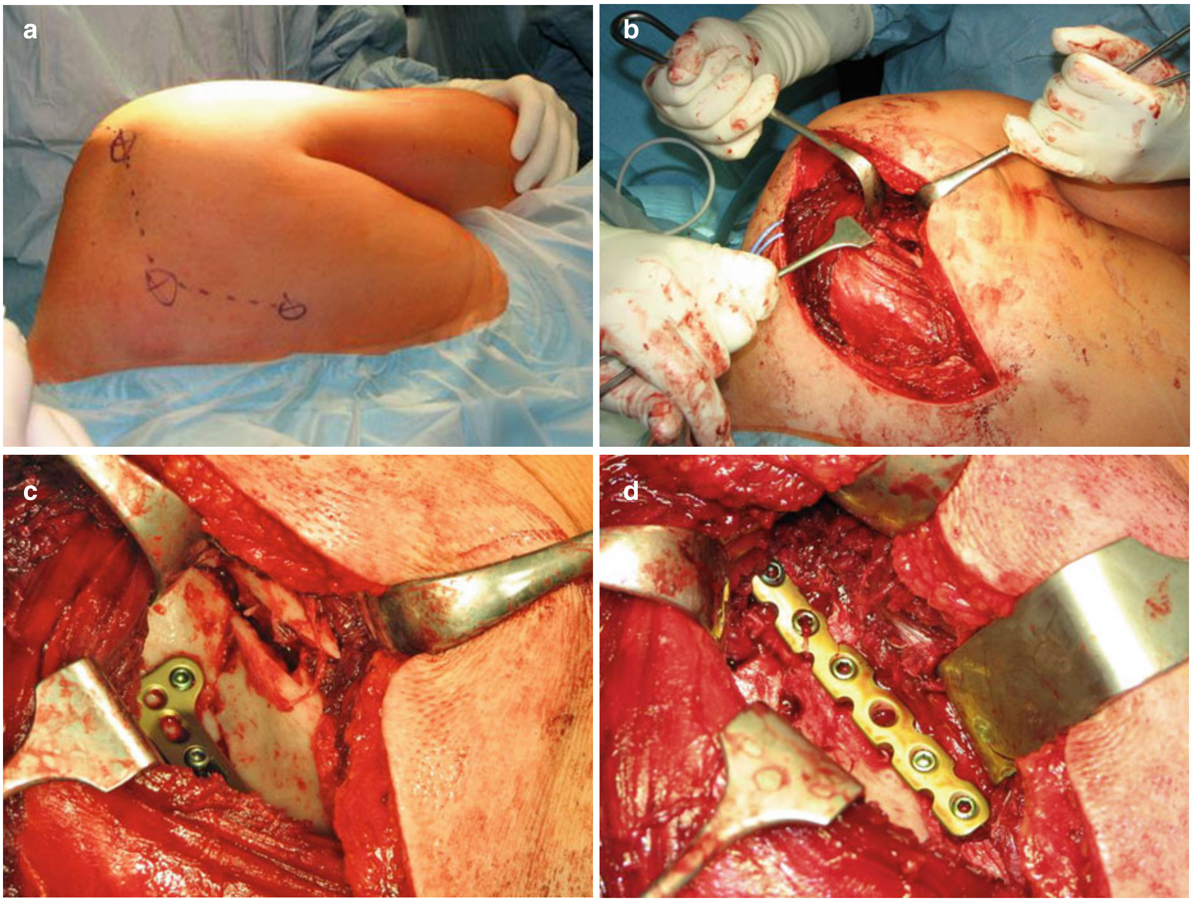

Fig. 6.5 Posterior approach (Judet's approach) to the scapula. The lateral decubitus position is shown in (**a**) with the incision line from the acromion angling down along the vertebral border of the scapula. The intermuscular interval between the M. infraspinatus and the M. teres minor is demonstrated in (**b**), offering access to the addressed region of the scapula. The fracture, reduction, and osteosynthesis with two plates are shown in (**c**) and (**d**)

necessary (Fig. 6.5). Different regions of the scapula are then reached through specific intermuscular intervals. Depending on the addressed region of the scapula, several modifications of this posterior approach have been described [1], such as a straight, limited incision or an incision along the Margo lateralis [10].

For anterior approaches, the patient should be operated in the beach chair position. For posterior approaches, the lateral decubitus position is preferred by the authors, although other positions such as the prone position are common as well. For fixation, generally plates and single screws are used. The authors recommend the use of 2.7-mm or 3.5-mm plates for the fixation of fractures of the scapular body and neck through a posterior approach; the use of locking plates seems to be advantageous for most injury patterns. Examples are shown in Fig. 6.6. For fractures of the glenoid, a sufficient fixation might be achieved with single screws.

6.6.2 Postoperative Rehabilitation

Immediate postoperative care includes a thorough control of wounds and a removal of drainages. Postoperative immobilization should not exceed the early postoperative phase (2–3 days), and passive rehabilitation by the physiotherapist should be initiated similar to the protocol of conservative management. If the surgeon is convinced of a high primary stability of the fixation, the passive range of movement can be increased quickly to emphasize the following active-assisted training. However, the strengthening and endurance training should not be started before postoperative week 6, and a strict radiographic follow-up should be provided by the surgeon. After 3 months, the patient should be able to return to their daily activities without significant restrictions and sport activities should be allowed.

6.7 Results

There is a multitude of studies reporting on complications and results of conservative and operative treatment of scapular fractures. The complication rate is reported to be between 1 and 4 %, with infection, shoulder stiffness, nerve injuries, heterotopic ossifications, and implant failure being the most commonly reported problems of an operative treatment. As described in a review [11] of 163 patients with surgical treatment of scapular fractures included in 12 studies, good and excellent functional results are obtained in approximately 85 % of the patients. Extraarticular fractures seem to have a better outcome than displaced fractures of the glenoid. Comparable good results are reported for the conservative treatment of scapular fractures.

In summary, the complexity of the scapular injury, stability, displacement, and an intraarticular fracture seem to have a negative effect on the overall functional outcome, although no studies provide definitive proof of the optimal treatment and most studies can not be compared, mostly because of study groups with different injury patterns.

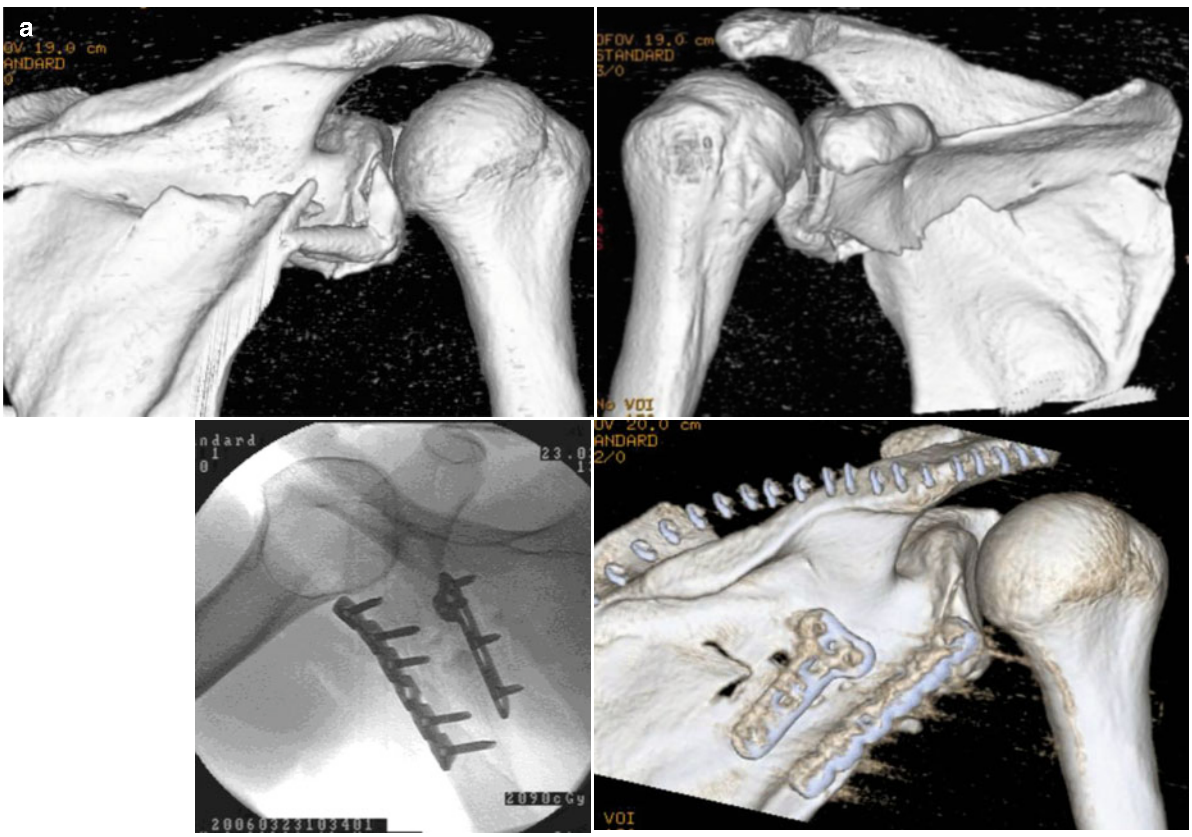

Fig. 6.6 (**a**) A 29-year-old patient with a dislocated, intraarticular fracture of the scapular body and the glenoid. Open reduction and osteosynthesis with two plates via a Judet's approach with the postoperative radiographic results is shown in the two lower pictures. (**b**) A 66-year-old patient with an unstable fracture of the scapula neck treated by open reduction and osteosynthesis with an interlocking plate (VARIAX-foot, Stryker®). (**c**)A 60-year-old patient with an unstable complex shoulder injury involving the scapular neck and an injury of the acromioclavicular joint treated with an open reduction and osteosynthesis with a small-fragment plate and a hook plate

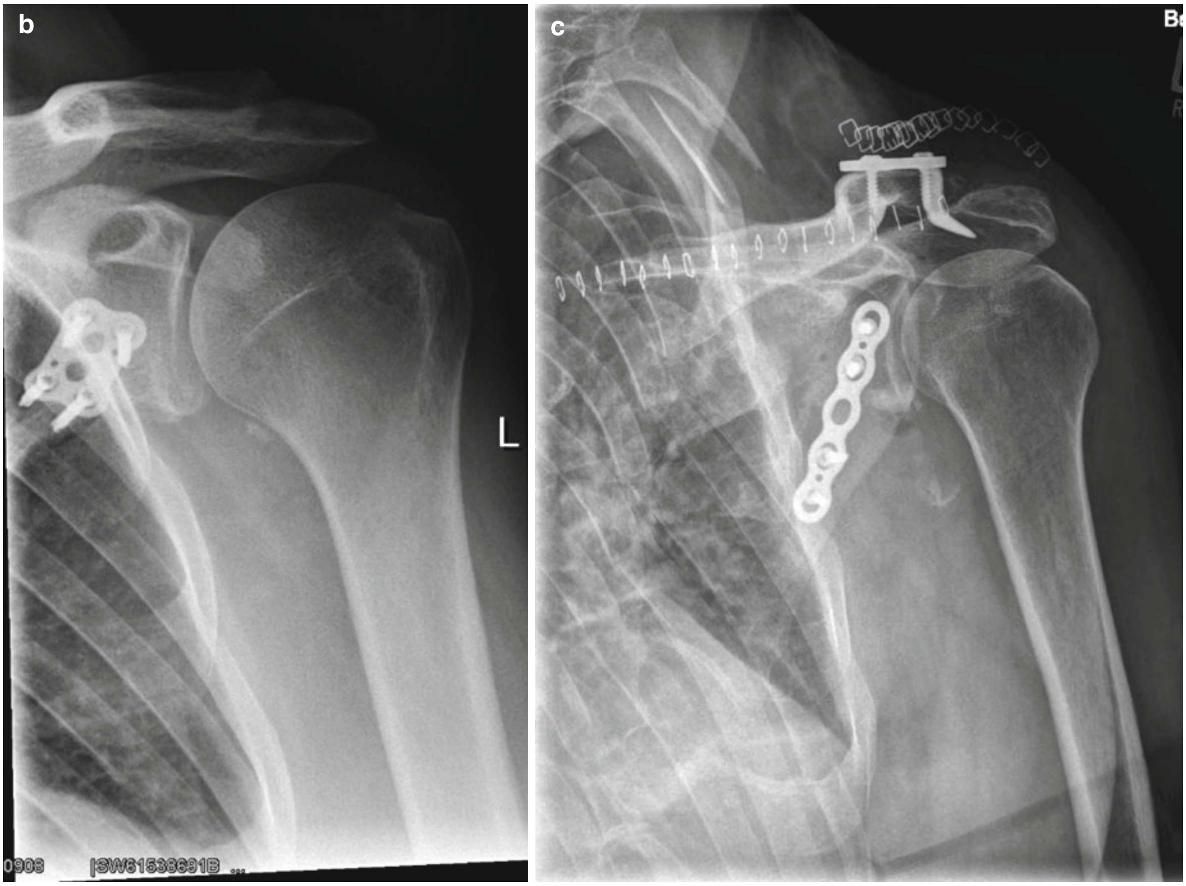

Fig. 6.6 (continued)

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Humeral Shaft Fractures

7

Pol M. Rommens

7.1 Introduction

Humeral shaft fractures account for approximately 7 % of all fractures in adults. They occur after direct trauma such as traffic accidents or after indirect, rotational trauma in sports accidents or falls at home. There are two peaks of incidence in the adult population: the young male and the older female. The first patient typically is the victim of high-energy trauma with multiple lesions, a more severe humeral fracture type and concomitant soft tissue damage. The latter patient suffers a solitary lesion and is the victim of a low-energy accident such as a fall from a standing or sitting position. The fracture type is then simple and there is no or minimal soft tissue damage. As pain is always severe and inability of use complete, there is an acute need of stabilization of the injured upper arm. Treatment modalities and principles have significantly changed during the last decades, as a response to the changing functional demands of the population and as a result of improvement of operative techniques and implants.

7.2 Diagnosis

Patients present with heavy and acute pain in the upper extremity. There is axial deviation and rotational deformity due to the fracture. The upper arm may be shortened. Local swelling and hematoma at the fracture site or of the whole upper arm are visible. Soft tissue trauma generally is minimal to moderate, the soft tissue mantle closed. In less than 10 % of cases, severe open or closed soft tissue damage is present.

Associated neurovascular damage is a common complication and should be looked for at admission of every patient. Radial nerve palsy is seen in more than 10 % of cases, especially in fractures of the middle and lower third. Isolated median and ulnar nerve palsy are rather seldom, more often they are part of a brachial plexus lesion. Brachial artery lesion or rupture is the exception; they are always the sign of a high-energy trauma (e.g., penetrating trauma, gunshot injury). As the brachial artery is the only vessel of the upper extremity, there must be a high index of suspicion for absence of pulse in the radial or ulnar artery or distal ischemia. Brachial artery repair is an emergency and must be considered together with the stabilization of the humeral shaft fracture.

Diagnosis is made by conventional X-rays in two planes perpendicular to each other, including the shoulder and elbow joint. X-rays must be read carefully in order to recognize or exclude secondary fractures or fissures extending into the adjacent joints. Further examinations are not necessary. CT examinations, three-dimensional views, and MRI are not helpful in the acute phase. They are useful in cases with delayed healing, pseudarthrosis, or deep infection.

Conventional X-rays cannot be the only tool; diagnosis is only complete when the study of the X-rays is combined with a thorough examination of the surrounding soft tissues and a neurovascular status is made, before any treatment is started.

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7.3 Classification

Fractures of the humeral shaft are classified as 1.2 lesions in the comprehensive classification of the Association for the Study of Internal Fixation (AO-ASIF). We distinguish three categories of fractures: types A, B, and C. From A to C, the fracture configuration becomes more complex and the number of fracture fragments and instability increases. Fractures of type A have the most simple configuration. After reduction, there is complete contact between the main fracture fragments. Type A1 is a spiral fracture, type A2 an oblique fracture (obliquity less than 45°), and type A3 is a transverse fracture. In the type B lesions, there always is a third fracture fragment. After reduction, the contact between the main fracture fragments is incomplete. Type B1 is a spiral fracture with an third spiroid fragment, type B2 an oblique or transverse fracture with an additional wedge fragment, and type B3 fracture an oblique or transverse fracture with several additional wedge fragments. Type C lesions are the most complex fracture types. After reduction, there is no contact between the main fracture fragments. Type C1 is a double spiral fracture, type C2 a segmental fracture, and type C3 a multifragmental or comminuted fracture.

Closed soft tissue damage is classified in accordance with the system of Tscherne; open soft tissue trauma in accordance with the classification of Gustilo.

7.4 Treatment Modalities

As fractures of the humeral shaft are unstable, painful, and hinder normal functioning of the whole upper extremity, there is an acute need for stabilization. This is usually achieved by putting the upper extremity at rest in an adduction bandage, attached to the thorax. Depending on the fracture configuration, personality of the patient, functional demands, and patient cooperation, different treatment modalities will be considered, each one with its specific advantages and drawbacks. There is a spectrum of options available for humeral shaft fractures, from conservative treatment, closed reduction and external fixation, and closed reduction and internal fixation, to open reduction and internal fixation. They will be discussed below.

7.4.1 Conservative Treatment

With the great advantages of operative fracture treatment in mind, Lorenz Böhler [1] stated that humeral shaft fractures should always be treated conservatively. They have a good healing tendency as the bone is circumferentially covered by muscles and receives excellent blood supply. As a non-weight-bearing extremity, perfect alignment is not needed. Axial and rotational deviations and also shortening up to 2 cm are well tolerated cosmetically and compensated functionally by the adjacent shoulder and elbow joint. The upper arm is adequately stabilized in different manners. In the acute phase, a circumferential bandage around the thorax, including the broken arm, or a Gilchrist bandage with the upper arm in adduction and endorotation is sufficient. The upper arm also can be aligned with a plaster of Paris splint, which is attached dorsally from the axilla to the wrist. If a fracture is situated between the rotator cuff and the pectoralis muscle, the humeral head will be abducted and internally rotated. If the fracture lies between the pectoralis muscle and the deltoid muscle, the proximal fragment will be adducted and the distal fragment laterally displaced. If the fracture line is situated distally from the deltoid muscle, the proximal fragment will be abducted. In case of a fracture proximal to the brachioradialis and the extensors, the distal fragment will be rotated laterally. After alignment and splinting, the whole arm is brought in adduction and endorotation and hanged in a collar and cuff. Sometimes, adduction of the upper arm is not possible as axial deformity in the fracture recurs. In this situation, stabilization in slight abduction is needed. The so-called hanging cast with a weight attached to the lower arm is not recommended as it gives distraction in the fracture site and hinders uneventful healing. It can only be considered as a temporary measure to achieve acceptable alignment of fracture fragments.

After 1 or 2 weeks, when swelling and pain subside, the plaster of Paris and adduction bandage is replaced by a functional brace until fracture healing [2]. Passive and active-assisted movements of the shoulder and elbow joint are followed by active motion to prevent stiffness. Rotator movements of the upper arm are allowed only when bridging callus is visible at the fracture site.

Literature data give high numbers of uneventful healing after conservative treatment, with nonunion rates below 5 %. Average healing time is not longer than 3 months. Nevertheless, few data are available on shoulder and elbow function and of muscle force at the end of treatment [3].

Conservative treatment remains a valid method of treatment in acute humeral fractures, when the patient is informed and consents with common drawbacks such as long immobilization period, axis deviation and shortening, temporary muscle atrophy, and stiffness of the adjacent joints.

7.4.2 Operative Treatment

Conservative treatment is contraindicated in conditions where uneventful healing cannot be expected, in cases with a high suspicion of complications, or in patients who will not comply with the demands of successful conservative therapy. We distinguish absolute and relative indications for operative treatment. An absolute indication is a fracture associated with vascular damage, a severe open fracture, a humeral fracture in a polytraumatized patient, and unacceptable position of the fracture fragments after closed reduction [4]. A relative indication is a transverse, short oblique, or spiral fracture, bilateral lesions, a humeral fracture in a patient with an unstable thorax, fractures with extension into the shoulder or elbow joint, which need operative treatment, the combination of an upper with a lower arm fracture (floating elbow), a humeral fracture with a primary radial nerve palsy, extremely obese patients, and uncooperative patients (e.g., drug or alcohol addicts).

The reasons for operative treatment are obvious in all these categories. Fractures with damage to the artery need urgent operative revision for vascular repair. The fracture is stabilized in the same session. Open fractures need débridement and soft tissue cleaning to avoid wound infection. As wound healing is facilitated in a stable environment, fracture stabilization is needed. Polytraumatized patients profit from early stabilization of major instabilities such as fractures of the long bones. Stable extremities enable mobilization in and out of the bed as soon as the general condition allows it. Fractures at the proximal and distal end of the diaphysis especially tend to present unacceptable shortening or axis deviation. If axial deviation recurs after closed reduction, operative treatment should be performed. In cases of transverse or short oblique fractures, the area of bone contact may be too small and fracture instability too high for uneventful healing. In spiral fractures, direct bone contact may be prevented by intercalating muscle bellies. In bilateral lesions, conservative treatment makes use of both upper extremities for activities of daily life impossible. In patients with unstable thorax, normal breathing is additionally hindered by the adduction bandage. If a fracture of the humeral head or an intraarticular fracture of the distal humerus is combined with a humeral shaft fracture and needs operative treatment, both lesions will be stabilized in one operative session. The same is true for the floating elbow: the humeral fracture will be stabilized in one session together with fixation of the lower arm. In obese or uncooperative patients, conservative treatment will be connected with a series of problems. Stability of casts or splints is low due to a thick soft tissue mantle; other patients may dismantle their bandage or throw it away. These and other problems can be avoided by early fixation of the fracture.

The humeral shaft fracture combined with primary radial nerve palsy is a specific entity, which will be discussed separately. There is an ongoing discussion as to whether the nerve needs operative revision and release together with stabilization of the fracture. Literature data are not convincing for any of the presented solutions.

Different approaches and techniques of stabilization are available for the fixation of humeral shaft fractures [5]. They will be presented consecutively with their advantages and disadvantages or possible complications.

7.4.2.1 Plate Osteosynthesis

Open reduction and internal fixation with plates and screws has been the method of choice for decades, when operative stabilization of humeral shaft fractures was indicated [6–8]. Anatomic reduction of fracture fragments and rigid fixation is possible with this technique, enabling quick postoperative active motion. As the cross section of the humeral shaft is round and small, parallel drilling of multiple screws through the plate holes in one long row enhances the risk of a fissure or secondary fracture line running through the drill holes. This may create additional fractures with break-out of the screws and plate, especially during rotator movement of the upper arm. Therefore, the use of a broad dynamic compression plate with screw holes in two rows instead of one or drilling of the screws in diverging directions is recommended. At least six to eight cortices should be taken by the screws at each side of the fracture. The plate can be used as a buttress; alternatively, compression is obtained in the fracture by eccentric positioning of some screws in the dynamic compression plate. In specific fracture configurations (spiral, long oblique, larger wedge fragment), lag screws are used separately or through the holes of the plate. In patients with osteoporosis, the use of an internal plate fixator with angle stable screws is recommended. The approach to the humeral shaft is dependent on the localization of the fracture. The course of nerves and vessels running near to the humeral shaft must be known precisely in order to avoid secondary, iatrogenic damage during surgery.

Fractures of the Proximal Third

The patient is placed in beach chair position or supine with the upper arm on a radiolucent side table. The larger fracture area must be visible under image intensification. The deltoidopectoral approach is chosen for these fractures. The skin incision starts below the coracoid process and runs S-shaped in the deltoidopectoral groove distally and laterally. The deltoid muscle is prepared laterally, the pectoralis, long biceps, and coracobrachial muscles medially. Damage to the cephalic vein is prevented by preparing it laterally together with the deltoid muscle. Other neurovascular structures are not at risk as they are at a distance from the approach. For better exposure of the fracture, the distal attachment of the deltoid muscle sometimes needs to be mobilized. The plate is carefully prebended and attached anterolaterally to the humerus (Fig. 7.1a–c). After plate fixation and rinsing, one Redon drain is placed, muscles are brought together with single stitches, and the subcutaneous tissue and skin are closed separately. A drain is removed the second day after surgery, and active motion is allowed as soon as possible.

Fractures of the Middle Third

The patient is placed supine with the broken arm on a radiolucent side table. The larger area of the fracture must be visible under image intensification. The deltoidopectoral approach as described for fractures of the proximal third is extended distally. The skin incision is curved in its upper part and is straight as it runs more distally. Proximally, the humeral shaft is exposed between the deltoid muscles laterally and the biceps, coracobrachial, and pectoral muscles medially. Distally, the anterolateral cortex of the humeral shaft is reached by longitudinal splitting of the brachial muscle. Special attention must be paid to the course of the cutaneous brachii and radial nerves. The first runs ventral to the brachial muscle, the last perforates the septum coming from the dorsal and going to the anterior and lateral muscle compartments. After plate fixation and rinsing, a single Redon drain is placed, muscle bellies are connected with single stitches, and the subcutaneous tissue and skin are closed separately. The drain is removed the second day after surgery, and active motion is allowed as soon as possible.

Fractures of the Distal Third

The patient is placed in a prone position with the broken arm in 90° shoulder abduction on a radiolucent side table and with the lower arm hanging down. The larger fracture area must be visible under image intensification. The skin incision runs strictly dorsally, in line with the humeral diaphysis, starting distally at the tip of the olecranon and going up as far as needed. Depending of the precise localization of the fracture, alternative deep approaches can be chosen. In fractures, located far above the olecranon fossa, the dorsal cortex of the humerus is exposed through longitudinal splitting of the triceps muscle. In more distal fractures, medial and/or lateral mobilization of the triceps muscle is recommended (Fig. 7.2a–c). In fractures with a very distal extension, olecranon osteotomy can be considered. Most challenging is the exposure and mobilization of the radial nerve, which crosses the dorsal cortex of the humeral shaft at the transition of its middle to distal third. Many times, placement of a plate between the radial nerve and the bone surface is needed. During fracture exposure, reduction maneuvers and plate placement, damage of the nerve by traction must be avoided. After plate insertion and rinsing, the triceps muscle is closed by single stitches. Two drains are placed, one in the triceps muscle, another in the subcutis. Subcutaneous tissue and skin are closed separately. The drains are removed the second day after surgery, and active motion is allowed as soon as possible.

Complications

Problems that are specific for plate osteosynthesis are seen after humeral plating as well. Other complications

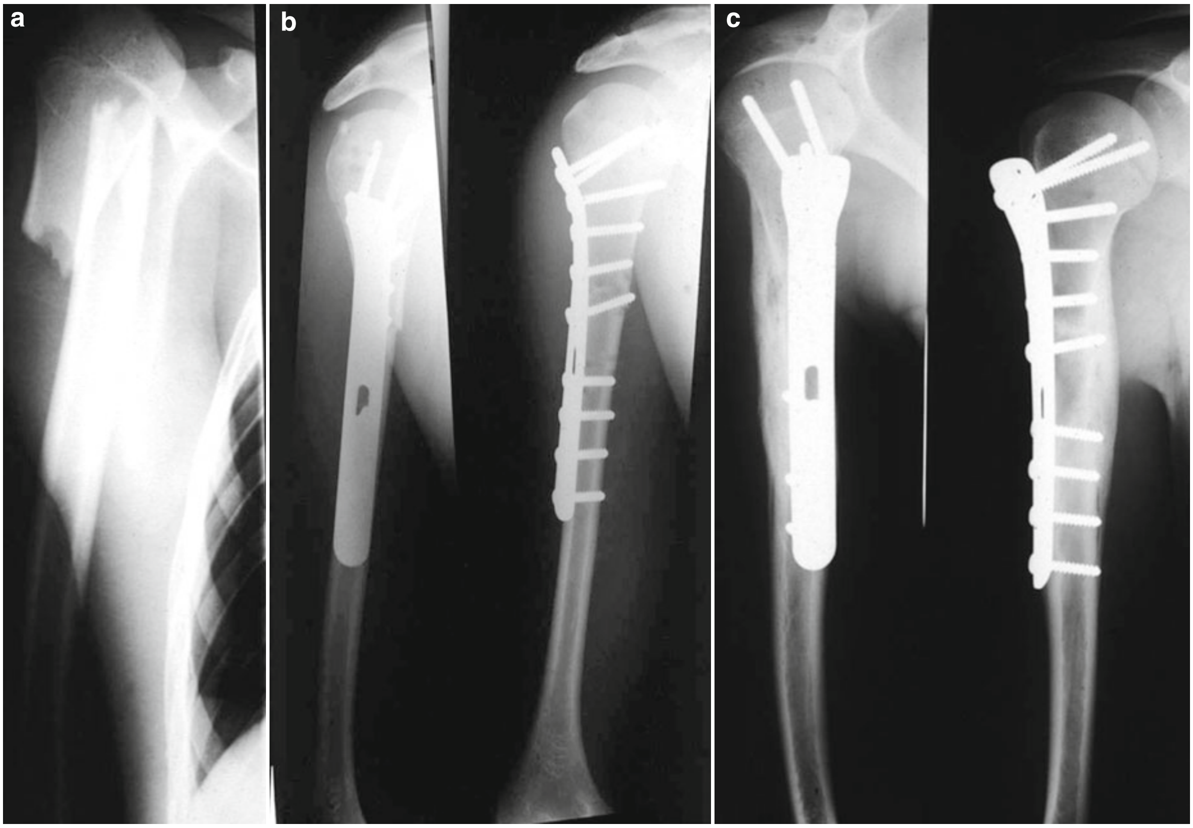

Fig. 7.1 (**a**) Proximal transverse shaft fracture with important shortening in a 15-year-old boy after bicycle collision. (**b**) Anterolateral plating. Postoperative AP and lateral views. (**c**) Control X-rays after 6 months. Free shoulder and elbow function

are typical for the region in which the surgery is done. Delayed healing and pseudarthrosis is seen in between 5 and 10 % of cases. The main reason is deprivation of blood supply of fracture fragments resulting from careless manipulation. Other reasons are distraction of fracture fragments or bone defect in comminuted fracture types. Bone necrosis resulting from severe trauma is less frequent. Screw loosening or plate breakage leads to instability in the fracture site with axial deviation and pseudarthrosis. The origin can be found in severe osteoporosis or a weak bone-implant construct caused by a short plate and a small number of screws. Reosteosynthesis always will be needed, in most cases combined with cancellous bone grafting [9]. Deep infection is rare thanks to the excellent soft tissue coverage of the humeral shaft. It is the consequence of primary, severe traumatic soft tissue contamination or careless surgery. Secondary radial nerve palsy is a specific complication of plate osteosynthesis of fractures in the distal third of the shaft. The nerve must be exposed and mobilized to bring the plate on the dorsal cortex. Prognosis is good in cases of neuropraxia, but recovery of function can take several months [10]. Damage to the ulnar and median nerves or to the brachial artery is a rare complication. After surgery, a neurovascular examination of the operated extremity is compulsory to exclude or confirm any damage to these structures.

7.4.2.2 Intramedullary Nailing

This technique of stabilization has become the standard of treatment of femoral and tibial shaft fractures. Healing usually is uneventful, functional recovery quick, and the rate of complications low. Although used for more than 50 years, intramedullary nailing of humeral shaft fractures has only been widely accepted in the last decade. Older intramedullary implants bear the name of their inventors: Rush pins, Ender, Hackethal, Prévot nails. Their common

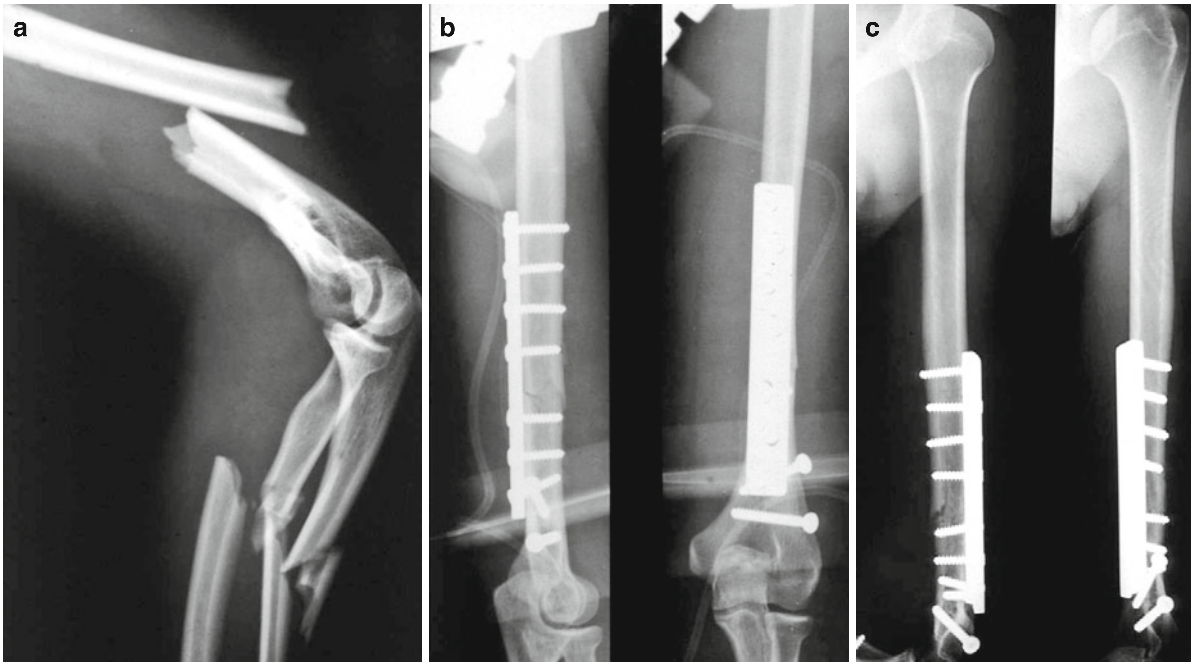

Fig. 7.2 (**a**) Floating elbow (distal humeral fracture and complete proximal lower arm fracture) of the *left side* in a 21-year-old male after car accident. Preoperative lateral view. (**b**) Dorsal plate osteosynthesis with broad DC plate. Additional lag screws for stabilization of intraarticular extension of the fracture. Postoperative AP and lateral views. (**c**) Control X-rays after 16 weeks. Free shoulder and elbow function

characteristic is that they are flexible, thanks to their small diameter, and noninterlocked implants. They are introduced in an antegrade or retrograde way through small entry portals in the metaphyseal region. When the whole medullary canal is filled up, the construction has an adequate stability. As the rods are not fixed to the bone, a common problem is their migration proximally or distally with perforation of the shoulder or elbow joint, instability due to loosening, and shortening caused by telescoping of the fracture fragments. Flexible nails are widely in use for stabilization of humeral shaft fractures in children and adolescents.

The different nails in use for adults are thicker, more rigid, and can be interlocked statically or dynamically. Sometimes interfragmentary compression can be obtained. Nails are available as solid, cannulated, or hollow implants. Thicker nails are inserted after reaming; thinner nails can be introduced without previous reaming. The nails can be introduced in an antegrade or retrograde way. The indications for both approaches are slightly different as well as their difficulties and drawbacks [11, 12].

Antegrade Nailing

Midshaft and more distal fractures are the best indication for this approach [13, 14]. In proximal fractures, adequate stability after antegrade nailing is only guaranteed by multiple interlocking of the humeral head fragment. The patient is placed in a beach chair position with the upper extremity on an arm support. The broken humeral shaft together with the shoulder joint must be visible on image intensification. The skin incision runs anteriorly starting from the lateral edge of the acromion and has a length of only 2 cm. The muscle fibers of the deltoid muscles are split, the subacromial bursa opened, and the supraspinatus tendon identified. The tendon is split carefully in line with its fibers and separated to expose the cartilage of the humeral head. The entry portal for the nail is situated medial to the attachment of the supraspinatus tendon in the lateral cartilage area of the humeral head. The nail is inserted with careful rotator movements until its point reaches the fracture line. Under image intensification, the fracture is reduced and the distal fragment picked up with the tip of the nail. The nail is further introduced until it reaches its final position. If the nail is cannulated, its correct length can be read at the inserted guide wire; in case of solid nails, the length has to be measured preoperatively at the opposite extremity or at the reduced broken arm. At the insertion point, the nail must not protrude the articular surface of the humeral head. Double interlocking is recommended at each side of the fracture (Fig. 7.3a–e). Distraction must be avoided in the fracture site. Closure of the fracture gap or interfragmentary compression can be obtained by the use of a compression device in some nail types. Correct position of nail and screws is controlled under image intensification in two planes. The supraspinatus tendon is closed with separate stitches. A drain is placed between the supraspinatus tendon and the deltoid muscle. The deltoid muscle, subcutaneous tissue, and skin are closed consecutively. The operated extremity is placed in a collar and cuff bandage. The drain is removed on the second day and active motion of shoulder and elbow is allowed as soon as possible. As stiffness of the nail-bone construction is the lowest in the rotational plane, rotator movements of the arm are forbidden until bridging callus is visible on the follow-up X-ray controls.

Retrograde Nailing

This approach is more demanding than the antegrade, but it has the advantage of being totally extraarticular [11, 15–18]. The best indications are midshaft and proximal fractures. Distal fractures are better nailed in an antegrade manner. The patient is placed in the prone position with the broken arm on a radiolucent side

Fig. 7.3 (**a**) Closed multifragmental fracture of the right humerus after motorcycle accident in a 27-year-old male. AP and lateral views. (**b**) Antegrade nailing with double interlocking in the proximal and in the distal fragment. Postoperative AP and lateral views. (**c**) Control X-rays after 4 weeks. AP and lateral views. (**d**) Control X-rays after 16 weeks. AP and lateral views. (**e**) Control after 1 year, before metal removal. AP and lateral views. Free shoulder and elbow function

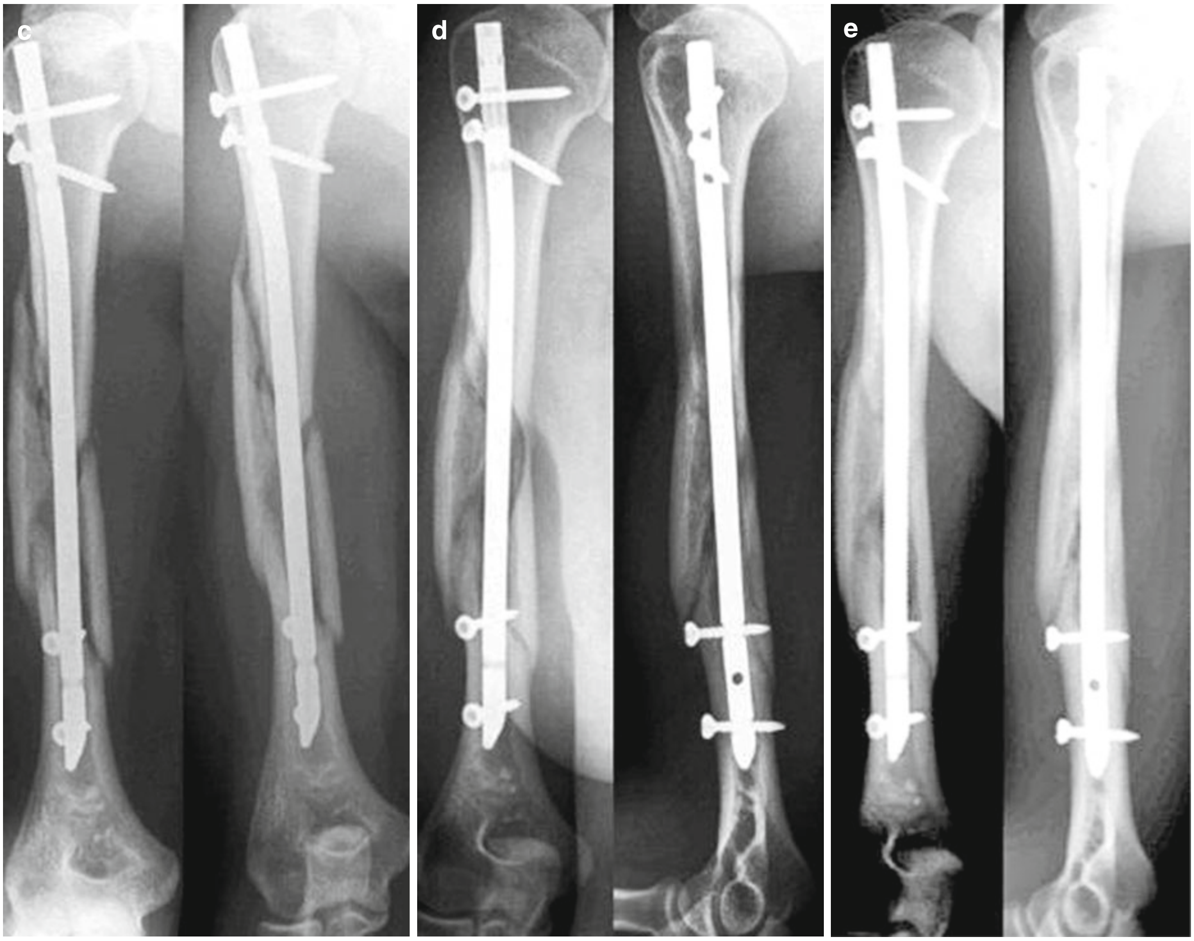

Fig. 7.3 (continued)

table and the lower arm hanging down. Before starting the procedure, one must make sure that the whole humeral shaft with the elbow and shoulder joint are visible in two planes with the image intensifier. A dorsal midline skin incision begins at the tip of the olecranon and runs 10 cm proximally. The triceps tendon is split longitudinally. The dorsal cortex above the olecranon fossa is exposed. An entry portal of 20 mm by 10 mm is made in the center of the triangle between the medial and lateral supracondylar ridge and the roof of the olecranon fossa. The distal humerus is prepared for nail insertion with hand reamers of increasing diameter. With careful rotator movements, the nail is inserted. Under image intensifier control, the proximal fragment is picked up with the tip of the nail. With hand force and further rotator movements, the nail is inserted until the tip reaches the proximal metaphyseal area. At least two interlocking bolts are placed at each side of the fracture (Fig. 7.4a–d). Wound irrigation and closure in different layers is performed. One Redon drain is placed at the entry portal. It is removed after 24–48 h. As in antegrade nailing, rotator movements are avoided until bridging callus is visible on follow-up X-rays. If the above-mentioned technique is strictly followed, the elbow and shoulder joint remain undisturbed. Ultimately, excellent shoulder and elbow function can be expected.

Complications

Damage to the rotator cuff and subacromial impingement are the most typical complications of antegrade nailing [19, 20]. They can be prevented by careful preparation of the entry portal and countersinking of the nail base below the level of the articular cartilage.

They result in chronic shoulder pain and loss of shoulder function. Damage to the axillary nerve is related to proximal interlocking. It can be avoided by meticulous dissection of the path between skin and bone for drilling and insertion of the bolt. Damage to the radial nerve may result from stretching of the nerve during manipulation of fracture fragments or false placement of the nail during nail insertion. If detected after surgery, the radial nerve should be revised as soon as possible to make sure its continuity is preserved and it is not intercalated between fracture fragments. A supracondylar fracture at the level of the entry portal in retrograde nailing is a major complication that leads to another osteosynthesis. Delayed union and nonunion are the consequence of suboptimal fracture alignment or low stability. In case of hypertrophic nonunion, stability must be enhanced. This can be obtained by exchange nailing with a thicker nail and interfragmentary compression; in hypotrophic pseudarthrosis stability is best obtained with compression plating [9, 21]. Cancellous bone grafting is also performed. Deep infection and vascular complications are rare after nailing.

7.4.2.3 External Fixation

Today, the spectrum of indications for external fixation is small. Accepted indications are severe open, contaminated fractures and infected fractures after previous treatment [22]. In selected patients with multiple lesions, primary and temporarily external fixation of a grossly unstable humeral fracture can be performed [23]. To avoid damage to the radial nerve, the pins of the external fixator are placed in the proximal and distal third of the humeral shaft. To avoid damage to the radial nerve, pins are never inserted in the middle third. In the proximal third, pins are placed from lateral to medial through the deltoid muscle. In the distal third, pins are placed from posterior to anterior through the

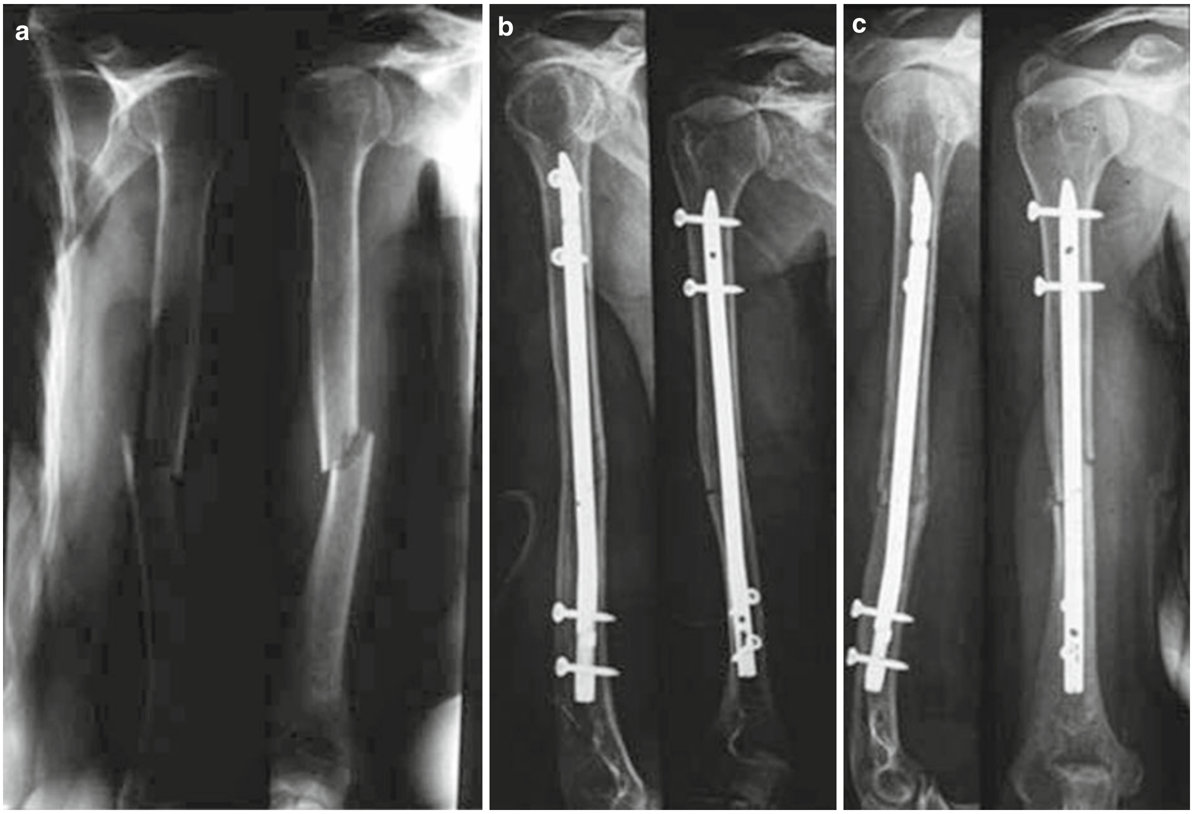

Fig. 7.4 (**a**) Closed oblique midshaft fracture of the left humerus in a 67-year-old woman after fall at home. AP and lateral views. (**b**) Retrograde nailing with double interlocking proximally and distally. No interfragmantary compression. Postoperative AP and lateral views. (**c**) Control X-rays after 4 weeks. AP and lateral views. (**d**) Control X-rays after 16 weeks. AP and lateral views. Free shoulder and elbow function

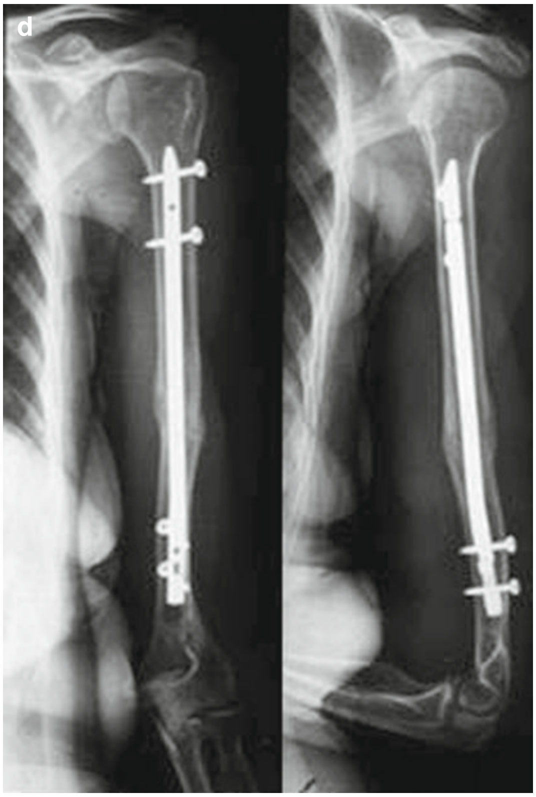

Fig. 7.4 (continued)

triceps muscle. Three pins are placed on each side of the fracture and connected with one or two bridging bars. Alignment is achieved by closed means. Wound management is done by regular debridements, wound irrigation, secondary wound closure, or split skin grafts with the external fixator in place. The fixator can be left in place until wound healing. The fixator can also be removed and stability achieved by plate osteosynthesis or nailing when no acute signs of infection are present. Because of the perforation of the deltoid and triceps muscle by the fixator pins, postoperative range of movement of the shoulder and elbow joint will be limited and mobilization painful.

Complications

As external fixator pins perforate skin and muscle bellies, they may be responsible for wound problems and pin track infections. In case of pin loosening, total stability of the construct diminishes. At the fracture area, this may lead to malalignment, delayed union, or nonunion. Fixator pins may perforate the brachial artery, the ulnar and median, and axillary nerve. Safe zones for pin placement must be considered. In very proximal or distal pin placement, the pins may perforate the shoulder or elbow joint with the danger of intraarticular infection.

7.4.3 Humeral Shaft Fracture with Radial Nerve Palsy

This special entity has been the subject of discussion for many years. Primary radial nerve palsy previously was not regarded as an indication for operative treatment as more than 90 % are caused by neuropraxia and recover after weeks or months with conservative measures. Some are in favor of early operative revision. The nerve is exposed at the level of the fracture site and directly sutured in case of axonotmesis. During the same procedure, the fracture is stabilized. The success ratio of this method of management is not significantly different from that of conservative treatment. If no clinical and electromyographic recovery of radial nerve function is observed after 3 months, operative nerve release with restoration of continuity is recommended.

In secondary radial nerve palsy, opinions do not differ. Secondary palsy can occur after closed fracture manipulation, or after plate osteosynthesis, nailing, or external fixation. Early revision of the nerve is recommended in all cases to ascertain nerve continuity and free trajectory.

Conclusion

Humeral fractures can be treated conservatively and operatively. There are absolute and recommended indications for operative treatment. There is a tendency toward more operative treatment for reasons of comfort, pain relief, and early functional recovery. Plate osteosynthesis remains a valid solution for most fracture types. Intramedullary nailing is gaining popularity as it is a less invasive and safe procedure in the antegrade and retrograde technique. External fixation only has exceptional indications. With careful soft tissue management and correct surgical technique, complications such as radial or axillary nerve palsy, subacromial impingement, or iatrogenic supracondylar fracture can be avoided. Uneventful healing can be expected in more than 90 % of patients when good fracture alignment and adequate stability is achieved by surgical or nonsurgical means.

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Distal Humerus Fractures

8

Klaus J. Burkhart, Pol M. Rommens,
and Lars Peter Müller

8.1 Introduction

Distal humerus fractures display seldom but severe injuries because of the complex distal humerus anatomy and often comminuted fracture types. They account for approximately 2–3 % of all fractures and for 17–30 % of fractures around the elbow. In younger patients, there is a predominance among males. The mechanism of accident is mostly a high-energy trauma in this population. In contrast, among elderly patients, distal humerus fractures concern mostly women with osteoporotic bone. Fractures are caused by a low-energy trauma such as a fall from standing height onto the outstretched or slightly flexed arm. These fractures are often severely comminuted. Because of the thin soft tissue envelope, many distal humerus fractures are open and additional injuries are common. The topographical proximity to the three main nerves and brachial artery are can lead to relevant lesions of these structures.

8.2 Diagnosis

The patient presents with severe pain at and possible deformation of the struck elbow. The elbow is checked for open wounds. Nerve and vessel injuries are excluded. Lateral and anteroposterior (a.p.) radiographs of the injured region are mandatory. The radiocapitellar view may be helpful in case of coronal shear fractures. For intra-articular fractures, a computed tomography (CT) scan is recommended to improve understanding of fracture morphology and preoperative planning. Duplex sonography and angiography are performed when an arterial injury is assumed. Alternatively, a CT angiography can be performed.

8.3 Classification

Although many different classifications have been published for distal humerus fractures, the AO classification is still the most commonly used classification system. Extra-articular fractures are graded as type A, intra-articular fractures affecting one column as type B, and intra-articular fractures affecting both columns as type C. Each type is subdivided in three more subtypes (Fig. 8.1).

Coronal shear fractures represent a special entity of distal humerus fractures. Dubberly in 2006 introduced a classification system based on three fracture types, that aims to give treatment guidelines:

Type I: capitellum fracture with optional involvement of lateral trochlear ridge

Type II: capitellum and trochlea fracture as on piece

Type III: capitellum and trochlea fractures as separate fragments, optionally comminuted

These fractures were further subdivided depending on the absence (A) or presence (B) of dorsal condylar comminution.

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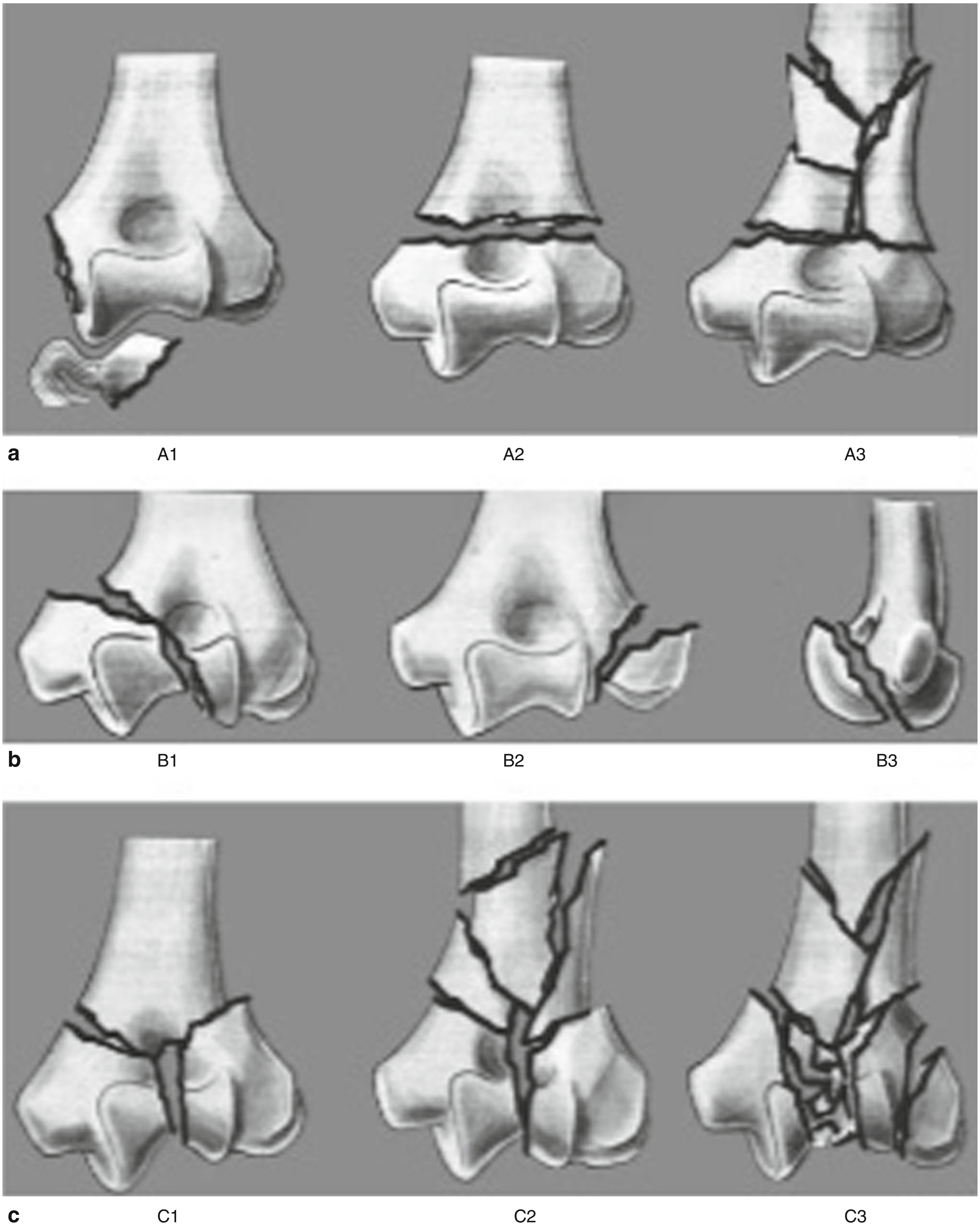


Fig. 8.1 AO-Classification of distal humerus fractures

8.4 Treatment

8.4.1 Conservative Treatment

As almost all adult distal humeral fractures are displaced, there is little place for conservative treatment. Because of the joint proximity of these fractures, functional bracing is not possible and joint immobilization of 6 weeks ends up in joint stiffness. Therefore, indications for conservative treatment are restricted to general contraindications for surgery, such as severe comorbidities or neurological diseases with an immoveable upper extremity.

In the seldom case of non-displaced coronal shear fractures a conservative treatment may be possible. A short period of immobilization should be followed by early functional treatment. However, close-meshed radiographic controls will be necessary to exclude secondary displacement. As coronal shear fractures of the distal humerus represent articular fractures the indication to ORIF should be made generously to provide an anatomic and stable elbow.

8.4.2 Operative Treatment

The aim of surgical intervention is the restoration of a painless and functional stable elbow joint to assure patients' independence in activities of daily living. Usually, these goals are achieved by open reduction and internal fixation (ORIF) with anatomical reconstruction of the articular surface of the elbow. To achieve these goals and to allow early physiotherapy, ORIF should be performed with double plate osteosynthesis. K-wire fixation does not provide sufficient stability. External fixation is used in multiple trauma patients and severe soft tissue injuries, which precludes an early internal fixation. Change to ORIF should be performed as early as possible to prevent elbow stiffness resulting from immobilization. Hinged external fixation may be helpful in case of insufficient stability despite adequate ORIF.

8.4.2.1 Open Reduction and Internal Fixation

Distal humerus fractures should be fixed as soon as possible within 1–2 weeks. Open fractures represent a case of emergency and should therefore be operated immediately. Surgical approach and implant use depend on the fracture type.

Type A.1: These extra-articular epicondylar fractures represent mostly avulsion fractures of the collateral ligaments or forearm muscles. These fractures are often displaced and, even if undisplaced, would need long-term immobilization in case of conservative treatment. Therefore, ORIF with lag screws is recommended using a lateral or medial approach. Using the medial approach, the ulnar nerve should always be exposed to avoid nerve damage.

Type A.2 + 3: These extra-articular metaphyseal fractures should be fixed through a dorsal approach using a double plating technique, which will be described in detail later. A minimum of three bicortical screws proximal and two screws distal to the fracture in both plates should be placed to provide sufficient stability. Monocortical screws may be used with locking plates. An olecranon osteotomy is not required. In selected cases, antegrade unreamed humeral nailing can be performed, if the distal fragment is large enough.

Type B.1 + 2: These intra-articular monocondylar fractures may be stabilized through a medial or lateral approach with lag screws in case of good bone quality. In case of osteoporotic bone, single plate osteosynthesis should be performed, optionally with a locking plate.

Type B.3: Several operative treatment options have been described for coronal shear fractures of the distal humerus. In former times fragment excision has been reported to gain good results. However, current literature supports ORIF whenever possible to restore the lateral column of the elbow. Fragment excision should only be performed in case of very small bony fragments or thin cartilaginous bowls. Excision of bigger capitellar fragments may lead to valgus instability – especially in medial collateral ligament insufficient elbow.

ORIF represents the treatment of choice in order to reconstitute an anatomic and stable elbow. According to Dubberly´s classification type I fractures can be faced through a lateral muscle splitting approach. Type II fractures require a more extensive lateral approach with lateral collateral ligament division in order to expose the lateral trochlea. Type III fractures necessitate a dorsal approach with performance of an olecranon osteotomy to ensure a sufficient overview of the whole distal humerus articular surface. In case of posterior comminution autologous bone grafting may be considered to support osteosynthesis. Several implants have been described for the maintenance of capitellar and trochlear fractures such as K-wires, cortical and cancellous screws of various diameters optionally in lag screw technique, bioabsorbable screws and pins, and headless compression screws. Biomechanical studies support the use of 4.0 mm partially threaded cancellous screws in posteroanterior direction as these could provide higher

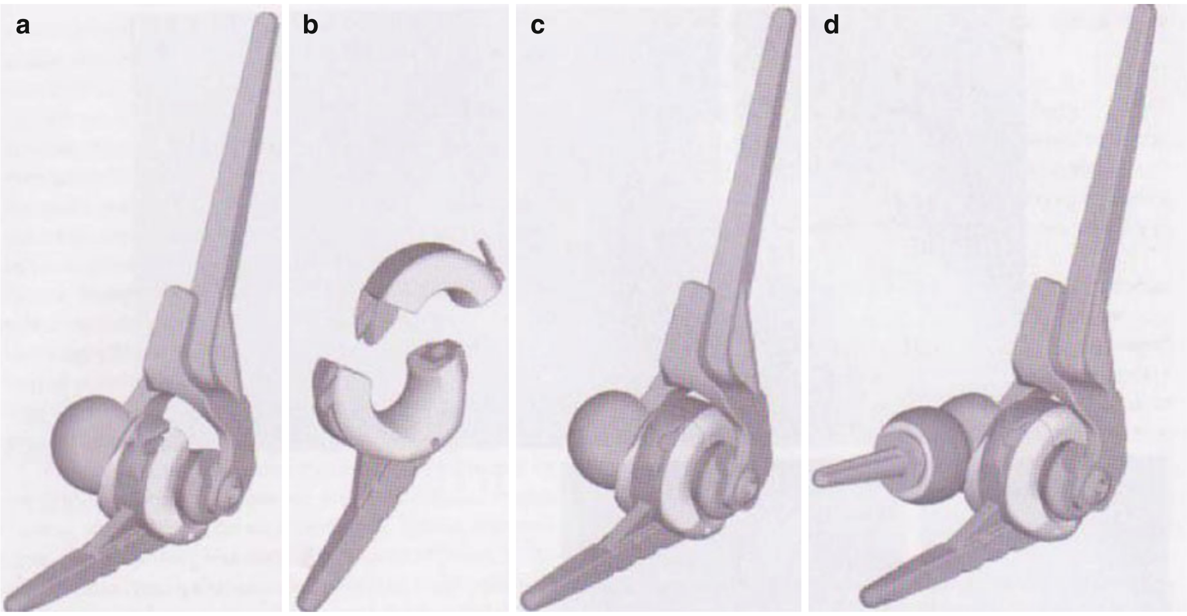


Fig. 8.2 The Latitude Total Elbow System (Tornier, France) is a modular, convertible implant. It allows the implantation of unlinked (**a**) and – by locking the ulnar component with the ulna cap (**b**) – linked (**c**) TEA and offers the opportunity of radial head replacement (**d**). Moreover, this system enables a resurfacing of the distal humerus only and can therefore be implanted as hemiarthroplasty. The aim of this prosthesis system is to reproduce and to mimic the elbow anatomy with reconstitution of the elbow kinematics. As it is a convertible implant, the Latitude HA can be transformed into a linked or an unlinked TEA at a later time point without a need for complete explantation of well-fixed components. With kind permission of Tornier

stability compared to first generation headless compression screws. However, more recent biomechanical in-vitro studies comparing conventional screws with new generation headless screws report equal or even higher compressive forces and stability whilst causing less cartilage damage for the headless compression screws. Threaded K-wires may be used to fix small fragments not amenable to screw osteosynthesis. Non-threaded K-wires should not be used due to their high risk of migration. Plate osteosynthesis may be performed in case of distinct posterior comminution. Stabilization of the coronal shear fractures may be performed arthroscopically by the experienced elbow arthroscopist, too. In the elderly patient with poor bone quality and fracture comminution, elbow arthroplasty may be required.

Type C.1–3: Intra-articular fractures are faced through a dorsal approach. The ulnar nerve is exposed and can be transposed anteriorly. Olecranon osteotomy is recommended to assure sufficient overview of the distal humerus articular surface. The articular surface should be reconstructed first. Afterwards, the articular surface block is fixed to the humeral shaft with two plates. In younger patients with good bone quality, nonlocking 3.5-mm reconstruction or 3.5-mm limited contact dynamic compression (LC-DC) plates may be used. Locking plates provide higher stability and are of advantage, especially in the elderly patient with poorer bone quality. Many implants and techniques have been described. Today, two techniques of double plating are mainly used: the Arbeitsgemeinschaft für Osteosynthesefragen (AO) technique with perpendicular plating and parallel plating introduced by O'Driscoll. The AO technique recommends perpendicular plating with one plate positioned medially on the ulnar column and one posterolaterally on the radial column. Long-standing experience exists for this technique and published series show excellent to good results. The concept of parallel plating is now recommended by some authors based on recent biomechanical studies, which reported significantly higher stability for parallel plating. Whether one of these techniques is superior to the other in a clinical setting is not known yet as no study exists comparing the two.

8.4.2.2 Arthroplasty

Comminuted distal humerus fractures in elderly patients with poor bone quality continue to pose a challenge to the treating surgeon. Complications such

Fig. 8.3 (**a**) TEA spool allowing linked or unlinked total elbow arthroplasty. (**b**) Hemiarthroplasty spool mimicking the articular surface of the distal humerus. With kind permission of Tornier

as nonunion as well as secondary loss of fixation occur frequently. Therefore, total elbow arthroplasty (TEA) is increasingly gaining interest in the primary treatment of distal humerus fractures. The rate of primary TEA implantation is increasing and short-term results are encouraging. As elbow arthroplasty is not a widespread procedure and experience is still lacking, it must be regarded as a salvage procedure restricted to specialized trauma centers. TEA with linked components is used in TEA when the epicondyles cannot be reconstructed and ligamentous stability is therefore not provided. Many prostheses have been introduced to the market and good results have been reported for all of them. Long-term results are not yet available. The latest generation of TEA is now offered as a modular system and allows an intraoperative decision of whether to use a linked or unlinked implant with or without radial head replacement. In case of ligamentous stability and good condition of the articular surface of the proximal ulna and radial head, even hemiarthroplasty can be performed (Figs. 8.2 and 8.3).

Frankle et al. [1] even reported that TEA revealed a better functional outcome with lower duration of surgery in elderly women with osteoporotic distal humerus fractures in comparison with ORIF. Moreover, a prospective study of McKee et al. [2] revealed better clinical results with lower reoperation rates in patients treated with TEA. Mighel et al. [3] reexamined 28 patients, who were converted to TEA after failed ORIF. They reported a significant improvement of the clinical outcome after TEA.

8.4.2.3 Postoperative Rehabilitation

The aim of internal fixation of distal humerus fractures must be a stable elbow that allows early active physiotherapy. A dorsal splint may be useful during wound healing. In case of complex fractures and/or poor bone quality, a longer time of splinting may be required, depending on the surgeon's impression of the achieved stability. However, passive physiotherapy out of the splint should be started as early as possible to prevent joint stiffness.

8.4.2.4 Complications

Poor results after ORIF of distal humerus fractures can be found in 20–47 %, according to the current literature. Immobilization longer than 10 days, secondary definitive reconstruction, delayed initiation of physiotherapy, and concomitant traumatic brain injuries are factors affecting the outcome adversely. Most common complications include infections (especially after open fractures), heterotopic ossifications, osteoarthrosis, nonunion, and instability as well as secondary loss of fixation.

8.4.3 Outcome

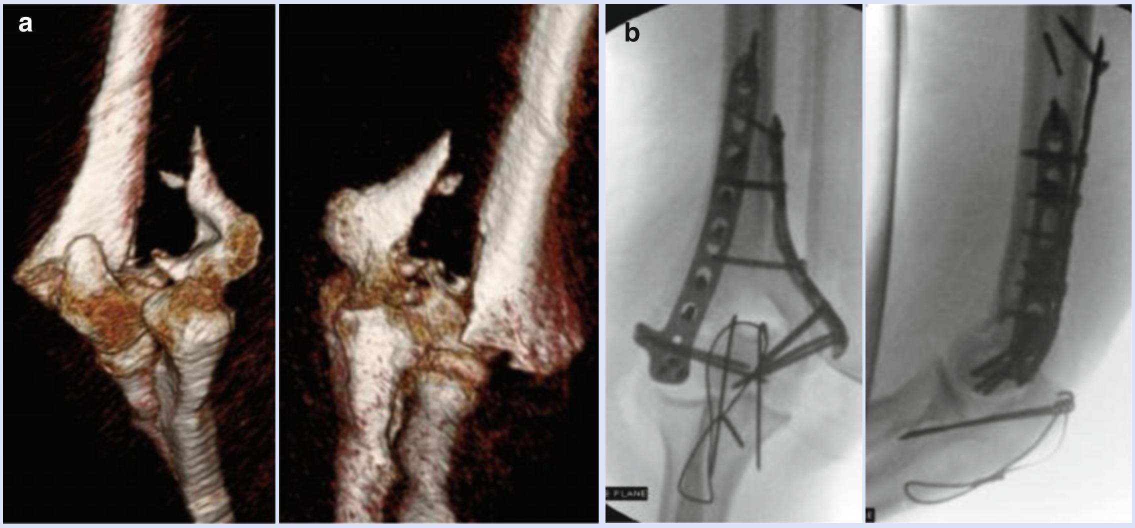
The aim of surgical intervention is the restoration of a painless and functional stable elbow joint to assure the patient's independence in activity of daily living. The functional arc of 100º, described by Morrey et al. [4] describes the range of motion (ROM) for the elbow that is needed to enable patients to fulfill activities of daily living. Usually the goals for this ROM are achieved by ORIF with anatomical reconstruction of the articular surface and stable fixation of the fracture area. In younger patients, good clinical results can be expected in as much as 80–90 %. A certain amount of joint stiffness is common, but the functional arc of 100º for extension/flexion as well as rotation is usually achieved.

Case 1

An 85year-old female suffered a Type-A.2 fracture as a result of a fall from standing height (**a**). The fracture was fixed with double plate osteosynthesis according to the AO technique using 2.7/3.5 mm precontoured locking plates (Synthes, Switzerland) (**b**). Olecranon osteotomy was not required. (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)

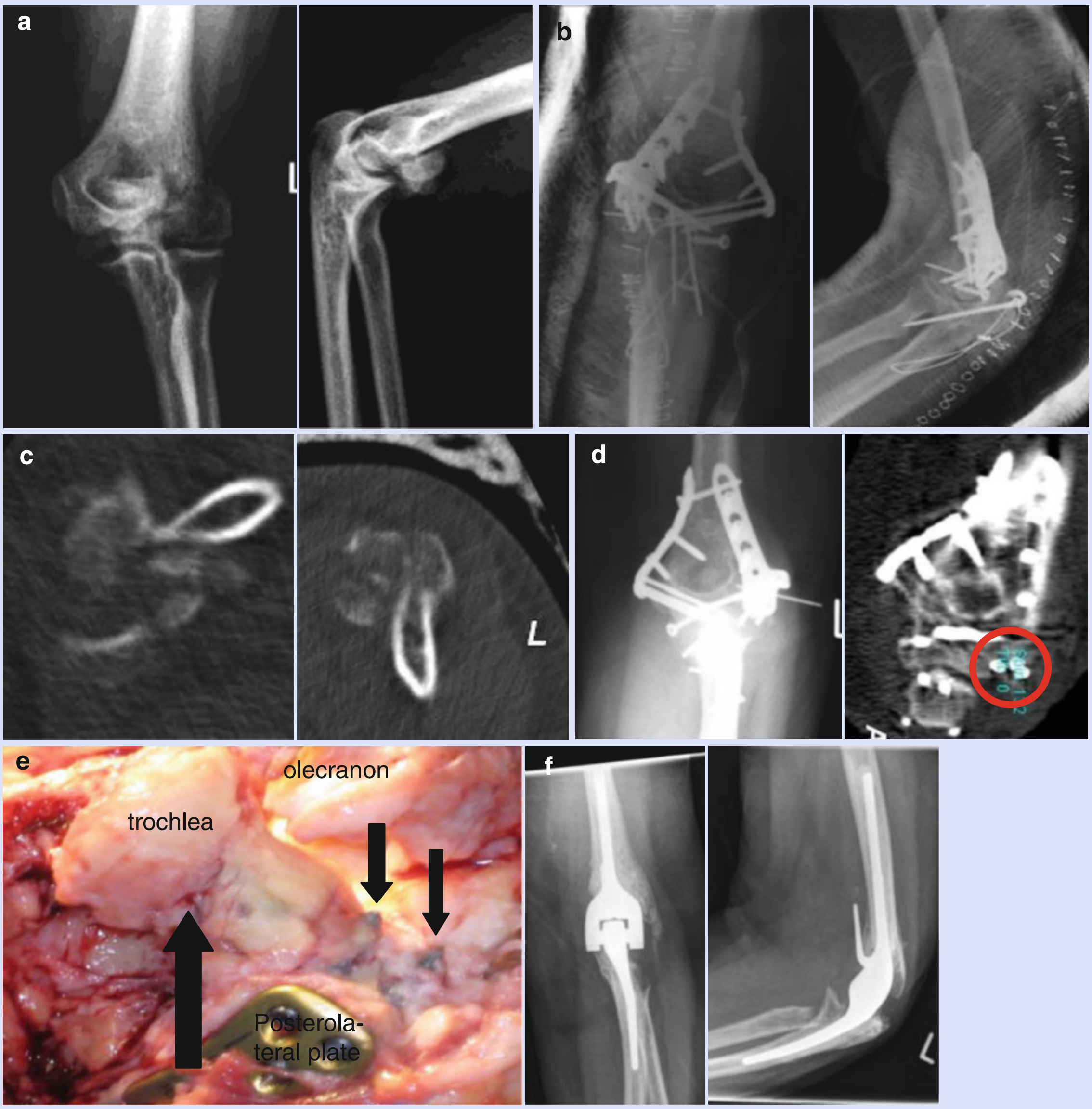
Case 2

A 47-year-old male suffered an AO C.3 fracture after a fall from a ladder (**a**). Olecranon osteotomy was performed and the fracture was fixed with double plate osteosynthesis according to the AO technique using 2.7/3.5 mm precontoured locking plates (Synthes, Switzerland) (**b**). (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)

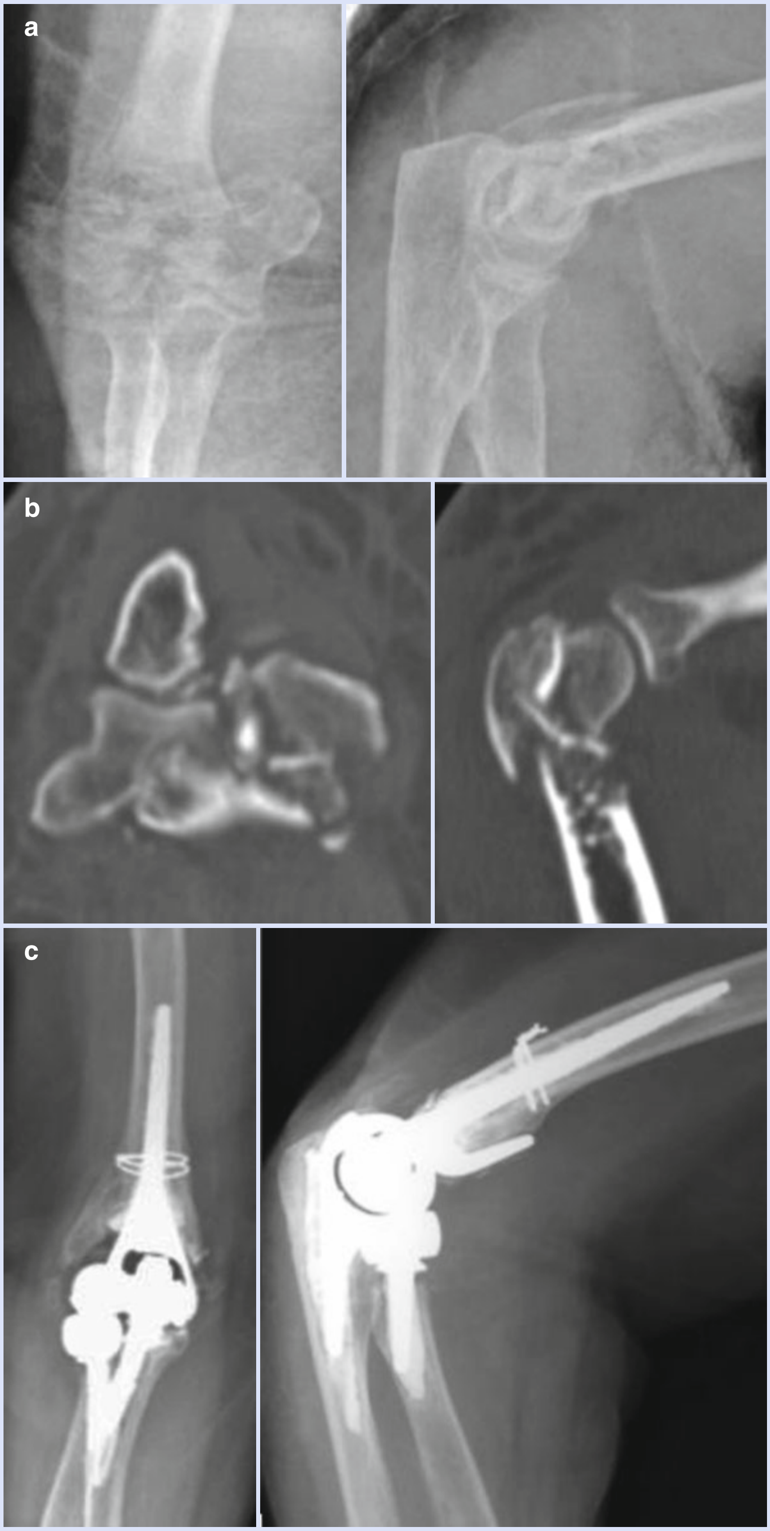


Case 3

A 70-year-old female with an AO C3 fracture (**a**, **b**) that was stabilized with double plate osteosynthesis according to the AO technique using 3.5 mm pre-contoured locking plates (Synthes, Switzerland) (**c**). She suffered secondary loss of fixation. The radiograph shows dislocation of the K-wire, the CT scan reveals the lacking capitellum with bare screws inside the joint (*ring*) (**d**). The intraoperative photograph shows these bare screws (two *arrows*) resulting from the dislocated capitellum and necrotic areas of the trochlea (*bold arrow*) (**e**). Conversion to TEA was performed with a Coonrad-Morrey prothesis (Zimmer, USA) (**f**). (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



Case 4
An 80-year-old female with a first-degree open AO C3 fracture of the distal humerus (**a**, **b**) was treated with linked TEA with radial head replacement. A humeral shaft fissure was stabilized with cerclage. (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



Case 5

A 70-year-old female with a C-fracture of the distal humerus was primarily treated with a lag screw and K-wire osteosynthesis (**a**). Olecranon osteotomy was not performed. K-wires do not provide sufficient stability and the patient developed a painful nonunion in malposition (**b**). When the patient was introduced to us, stable re-osteosynthesis of the articular surface was not possible. Hemiarthroplasty was performed using the Latitude system. The medial epicondyle was reconstructed and fixed with two lag screws to provide sufficient ligamentous stability (**c**). (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)

Conclusion

Distal humerus fractures in adults remain a challenging problem due to anatomic complexity of the articular surface, comminuted fracture morphology, and a short distal fragment. The goals of a painless, stable, and functional elbow are achieved by ORIF with anatomical reconstruction of the articular surface in younger patients. The maintenance of distal humerus fractures in elderly patients with poor bone quality remains problematic and controversial. Despite improvement of osteosynthesis implants, secondary loss of reduction, heterotopic ossifications, and nonunion are common complications. Elbow arthroplasty is gaining importance as it has been proven to achieve good clinical results. Because elbow arthroplasty is not yet a widespread procedure and experience is still lacking, it should be regarded as a salvage procedure limited to use in specialized trauma centers. Long-term results are not yet available.

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9 Coronoid Fractures

Klaus J. Burkhart, Pol M. Rommens, and Lars Peter Müller

9.1 Introduction

Fractures of the coronoid process of the ulna usually result from a fall on the outstretched hand with the elbow in extension to 20º of flexion with a posterolateral valgus or posteromedial varus stress. These are rare injuries that usually do not occur in isolation. They mostly emerge with elbow dislocations, often combined with radial head and olecranon fractures. According to the current literature, coronoid fractures can be found in 12–39 % of patients with elbow dislocations. Besides concomitant fractures, soft tissue lesions play a major role in the pathophysiology of coronoid fractures. The combination of a coronoid fracture, radial head fracture, and medial collateral ligament (MCL) tear is called the "terrible triad injury" of the elbow, emphasizing the severity of this injury resulting in gross instability if not treated adequately.

The coronoid process is an important stabilizer of the elbow joint for several reasons: Axial stability is provided by the coronoid functioning as buttress. It is well known that 40 % of the axial forces are conducted through the ulnohumeral joint. The anterior capsule attaches a few millimeters distally to the tip, the brachialis muscle inserts on the base, and the lateral collateral ligament (LCL) to the lateral side of the coronoid. The MCL inserts on the anteromedial facet, the sublime tubercle, and is the primary stabilizer against valgus stress. Fractures of the anteromedial facet are therefore assessed as a distinct entity now and are taken into account by O'Driscoll's classification of coronoid fractures.

9.2 Diagnosis

Patients present with swelling and pain of the injured elbow. In case of unreduced dislocations, the elbow is deformed. Neurovascular damages must be excluded and stability has to be assessed. Lateral and anteroposterior (a.p.) radiographs form the basis of the diagnostic investigation. Fractures of the anteromedial facet may present as a fracture of the sublime tubercle on the a.p. or as a "double crescent sign" on the lateral radiograph. Sometimes anteromedial facet fractures are misinterpreted as harmless tip fractures, because the oblique fracture component cannot be detected on the standard radiographs. As coronoid fractures can easily be missed or underestimated on plain radiographs, a computed tomography (CT) scan is recommended for the correct classification.

9.3 Classification

Coronoid fractures were first classified by Regan and Morrey in 1989:

Type I	Fracture of the tip
Type II	Fracture involves less than 50 %
Type III	Fracture involves more than 50 % of the coronoid

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Each type is subclassified according to the absence (A) or presence (B) of a dislocation (Fig. 9.1).

In 2003, O'Driscoll et al. [1] introduced a new classification system with special consideration of the anteromedial facet (Table 9.1). Type 1 fractures affect the tip, type 2 the anteromedial facet, and type 3 the base. Each type is divided into subtypes. Treatment options can be derived from this classification.

9.4 Treatment

Most coronoid fractures are small type I fractures of the tip. These can be treated conservatively. The treatment of larger coronoid fragments is usually operative, although the fracture may seem harmless on standard radiographs. As these fractures must be interpreted as fracture-dislocations in most cases, even fractures that appear harmless on standard radiographs may present severe injuries. Correct classification requires a CT scan. Not only the bony structures, but also the soft tissues have to be addressed during surgery.

Fig. 9.1 Regan and Morrey classification

Table 9.1 Classification of coronoid fractures developed by O'Driscoll et al.

Type	Fracture	Subtype	Description
I	Tip	1	≤2 mm of the tip
		2	>2 mm of the tip
II	Anteromedial facet	1	Anteromedial rim
		2	Anteromedial rim + tip
		3	Anteromedial rim + sublime tubercle + tip
III	Basal	1	Olecranon basal coronoid fractures
		2	Transolecranon basal coronoid fractures

A medial approach is used for the stabilization of isolated coronoid fractures. The ulnar nerve must be exposed, but not necessarily transposed. Additional lesions may require a different approach or additional approaches. In case of a radial head fracture, the coronoid may be stabilized via Kocher's approach before stabilization of the radial head. If the elbow is severely unstable, a posterior approach may allow addressing of all lesions with only one skin incision.

9.4.1 Type I

Only isolated small fractures of the coronoid tip type I.1 can be treated conservatively with a short period of immobilization followed by early functional therapy. If a small fragment dislocates into the joint, this loose body should be removed arthroscopically. A CT scan should be performed to ensure that the fracture is not underestimated, as these fractures appear small on the standard radiographs but average 39 % of the coronoid height and therefore include the capsular insertion. Additionally, they may involve the anteromedial facet. These fractures are unstable and should therefore be addressed operatively. If the fragments are large enough, screw fixation may be performed; smaller fragments are reattached with transosseous sutures. Type I fractures are typically part of terrible triad injuries (radial head fracture + coronoid fracture + MCL rupture). Smaller coronoid fragments must not be addressed if maintenance or replacement of the radial head leads to a stable joint. Fractures involving 20–30 % of the coronoid height should be stabilized in this setting. Anatomical reconstruction of all elements is necessary to prevent chronic instability. When stable fixation cannot be achieved, hinged external fixation is recommended to allow early functional therapy.

9.4.2 Type II

As these fractures involve the onset of the anterior bundle of the MCL, they are unstable. Fixation is required. Smaller fragments can be secured with sutures. Larger fragments can be stabilized with screws or a buttress plate through a medial approach.

9.4.3 Type III

Type III fractures represent severe injuries, often concomitant with additional fractures and extensive ligamentous damage. Anatomical reconstruction of the coronoid is the essential point in restoring a stable elbow joint. Screw and plate osteosynthesis is recommended. In case of type III.1 fractures with one or two bigger fragments, stable fixation usually can be achieved. In case of a more complex, comminuted fracture situation, especially coming along with transolecranon fracture dislocations, it may not be possible to obtain stable fixation with osteosynthesis alone. Hinged external fixation should be performed if there is any doubt regarding elbow stability. If the coronoid cannot be repaired, the olecranon tip or a fragment of an irreconstructible radial head can be used to replace it.

9.5 Postoperative Rehabilitation

Active and active-assisted physiotherapy should be initiated as early as possible. Time of splinting should not exceed 2 weeks. However, exercises should begin early postoperatively. Varus and valgus stresses as well as resistive exercises should be omitted for 6 weeks.

9.6 Complications

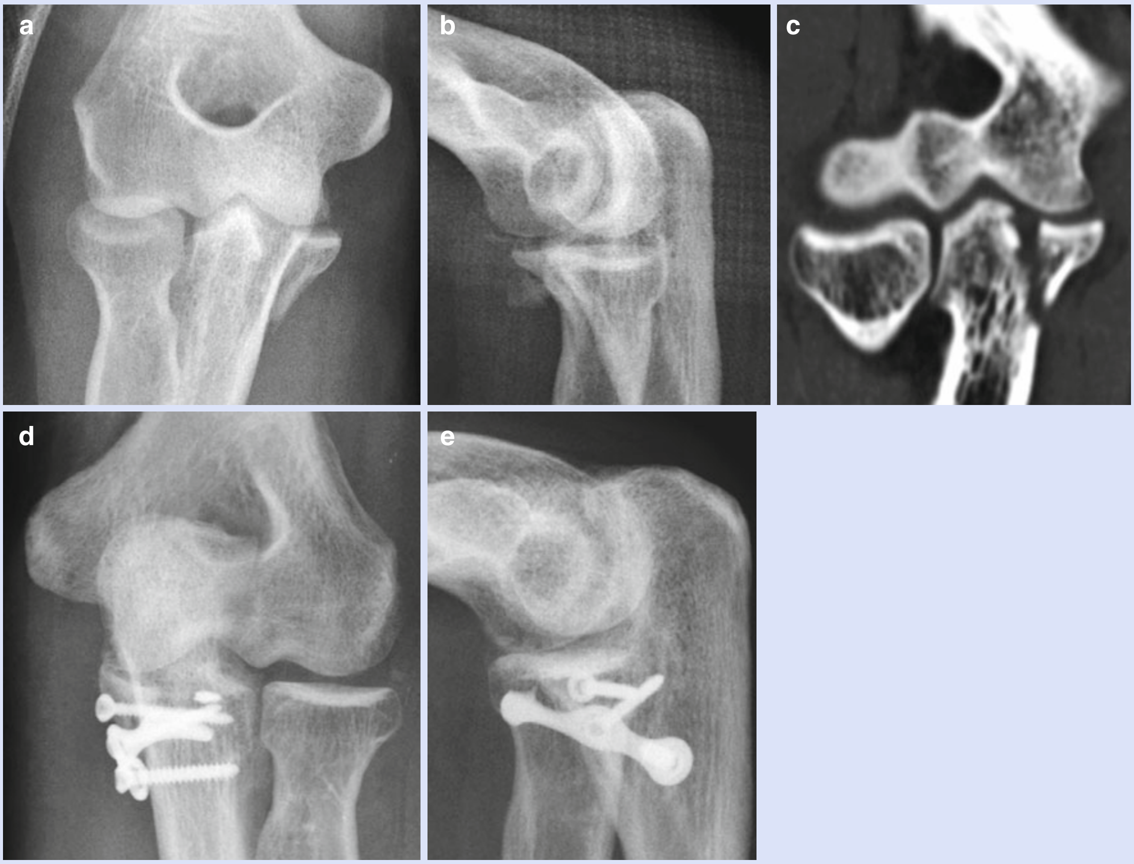
Complications are numerous with this kind of fracture, especially in case of terrible triad injuries and transolecranon fracture-dislocations. Poor clinical results can be found most notably with severe fracture types. Elbow stiffness and heterotopic ossifications represent the most common complications. Furthermore, ulnar nerve irritation, chronic instability, and joint incongruity can be seen. Elbow stiffness resulting from heterotopic ossifications, ulnar neuropathy, and as instability and incongruity are addressed by early revision surgery. Elbow stiffness resulting from capsular contracture should not be released before 6 months postoperatively. More or less severe osteoarthrosis can be observed in nearly all of the cases, but must not be symptomatic. Anatomic and stable joint restoration marks the best condition to avoid poor results.

Conclusion

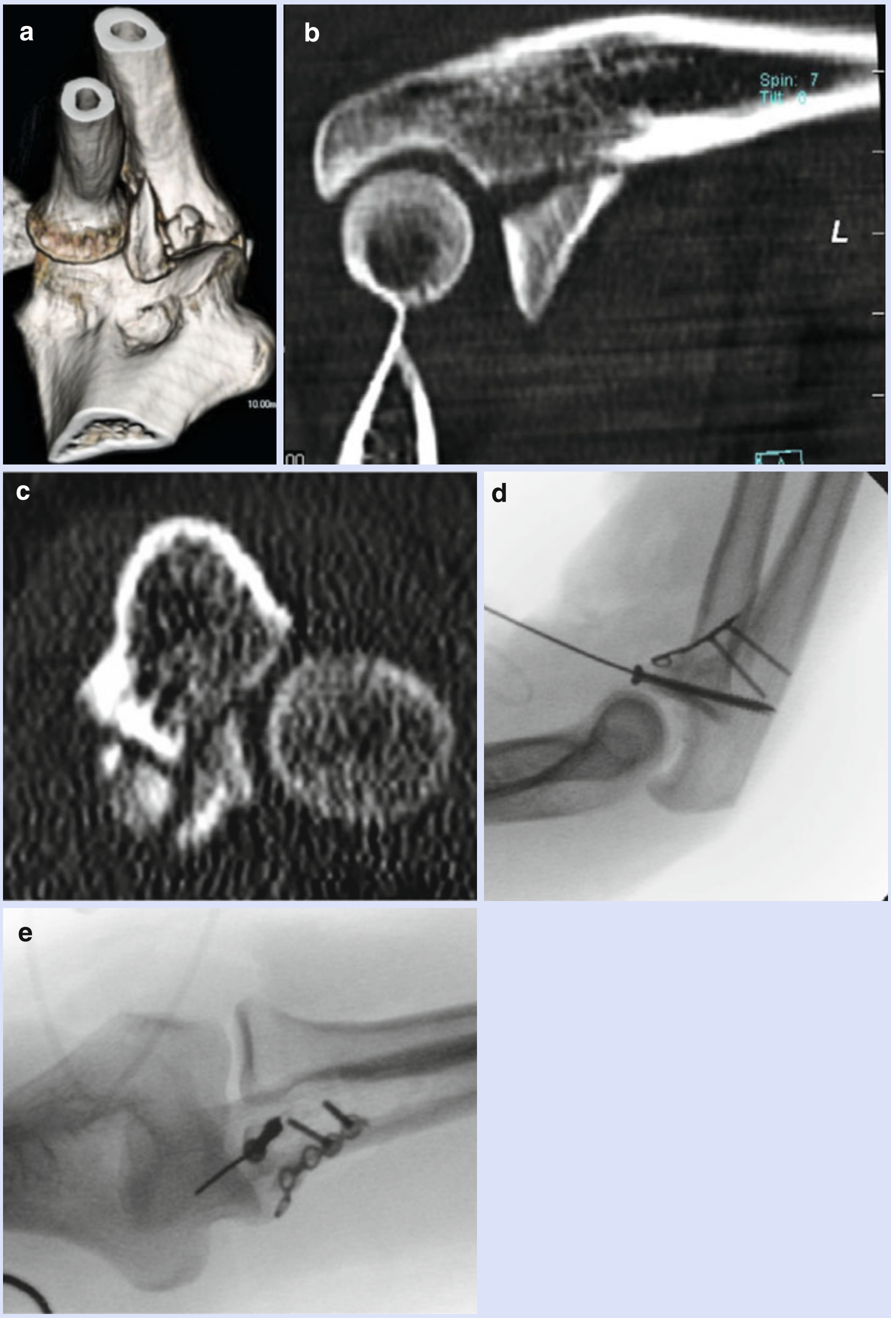
Fractures of the coronoid process of the ulna are rare injuries that usually do not occur in isolation. They mostly emerge with elbow dislocations. Correct diagnosis and classification of these fractures can be challenging. Especially smaller coronoid fragments can easily be underestimated or missed on standard radiographs. Fractures are classified either according to Regan and Morrey's or, more accurately, to O'Driscoll's classification with direct consequence to treatment strategies. As the coronoid process is an important stabilizer of the elbow joint, providing axial, varus and rotatory stability, initiation of the correct treatment is essential to restore elbow function and stability. The important role of the coronoid process for elbow stability has been increasingly recognized in recent years. Treatment guidelines have changed to a mainly operative pathway. The current concept is to fix all coronoid fractures that are associated with elbow instability. Only small tip fractures that are not associated with elbow instability may be treated conservatively. But even small coronoid fragments may lead to instability, as these often represent lesions of important soft tissues attachments. Early diagnosis and correct classification of coronoid fractures often require a CT scan. They are essential to restore normal elbow function and stability.

Case 1

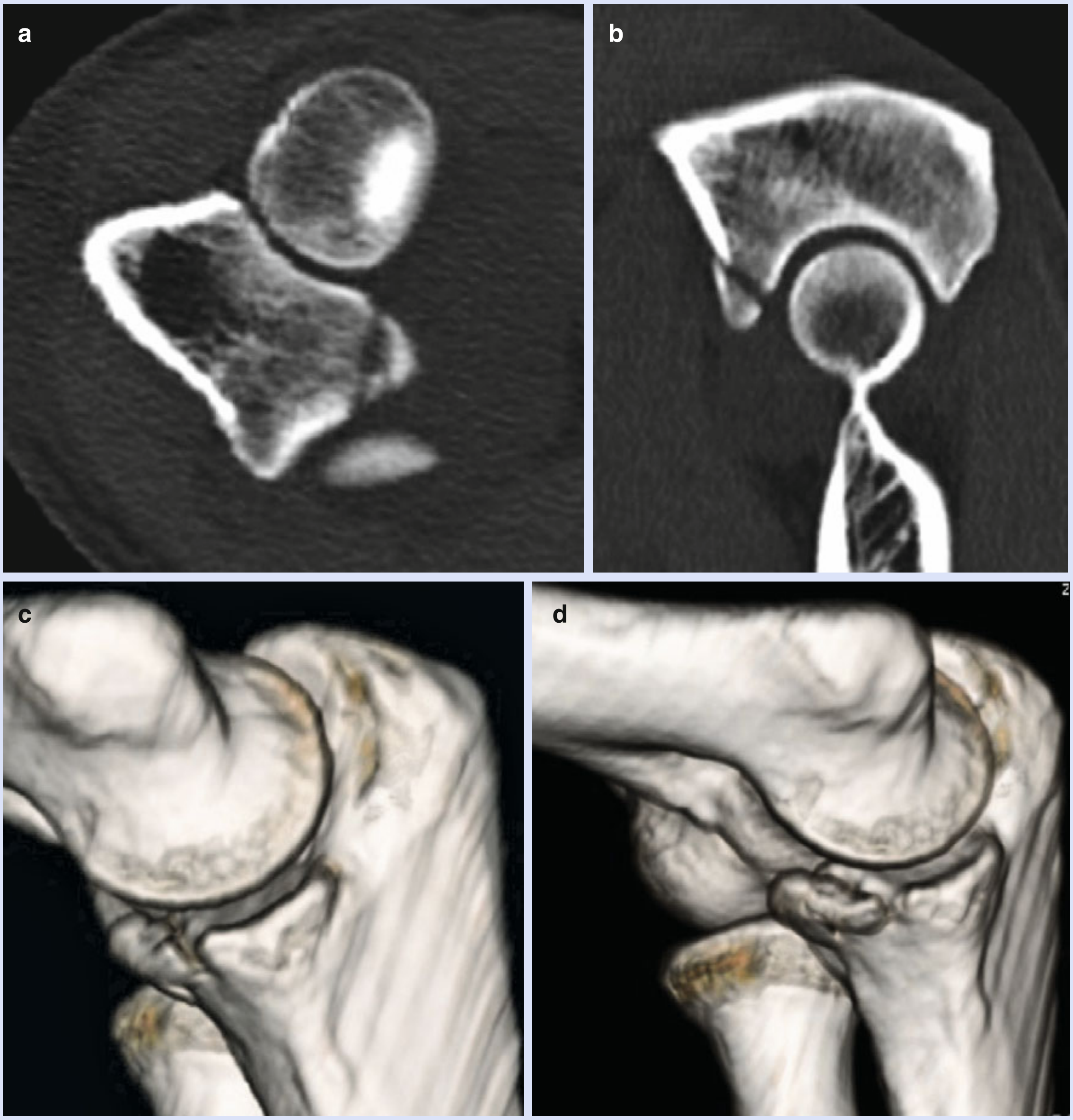
Fracture of the anteromedial facet + coronoid tip + sublime tubercle (III.3) (**a–c**) stabilized with a plate (Acumed, USA), a free screw, and a suture anchor (**d** and **e**). (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



Case 2
Patient with type III.1 fracture (**a**–**c**) stabilized with a cannulated screw and a buttress plate (**d** and **e**). (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



Case 3
Conservatively treated patient with I.1–I.2 coronoid fracture. The CT scan and 3D-reconstructions nicely show the tip fracture with an intact sublime tubercle. (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



Reference

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Olecranon Fractures

10

Tobias E. Nowak and Pol M. Rommens

10.1 Introduction

The subcutaneous location of the olecranon makes it vulnerable to trauma. Olecranon fractures are a common injury, comprising 10 % of all upper-extremity fractures. The mechanism of injury can include direct trauma, overload applied by the triceps, or forced hyperextension. Most fractures of the olecranon have a favorable prognosis following treatment.

10.2 Anatomic Considerations

The olecranon is the most proximal posterior eminence of the ulna. It is on the dorsal subcutaneous border of the elbow joint and contains broad attachments for the triceps tendon posteriorly. Anteriorly, the olecranon, together with the coronoid process, forms the greater sigmoid or semilunar notch of the ulna, which articulates with the trochlea. A transverse "bare" area devoid of cartilage is found at the midpoint between the coronoid and the tip of the olecranon.

10.3 Diagnosis

Patients complain of pain in the elbow joint with an inability to actively extend the elbow against gravity. Because of the closeness of the ulnar nerve, the examination should document the status of ulnar nerve function. Diagnosis is made by conventional X-ray of the elbow joint in anteroposterior (a.p.) and true lateral radiographs. The true lateral plane is used to determine the extent and nature of the fracture pattern. Combined lesions such as a radial head fracture or dislocation, coronoid process fractures, or distal humerus fractures should be excluded. The percentage of articular surface involved in the fractured proximal fragment, the amount of comminution, the fracture angle, and the degree of displacement are all critical in evaluating the injury and selecting the appropriate treatment.

10.4 Classification

Schatzker classified olecranon fractures according to the fracture pattern and the degree of displacement (Fig. 10.1). Simple transverse fractures are classified type A. Type B fractures are transverse fractures involving the mid third of the fossa olecrani with impaction. Intra-articular oblique fractures of the distal third of the olecranon fossa are classified type C. Type D fractures represent those with comminution. Type E fractures include oblique extra-articular fractures

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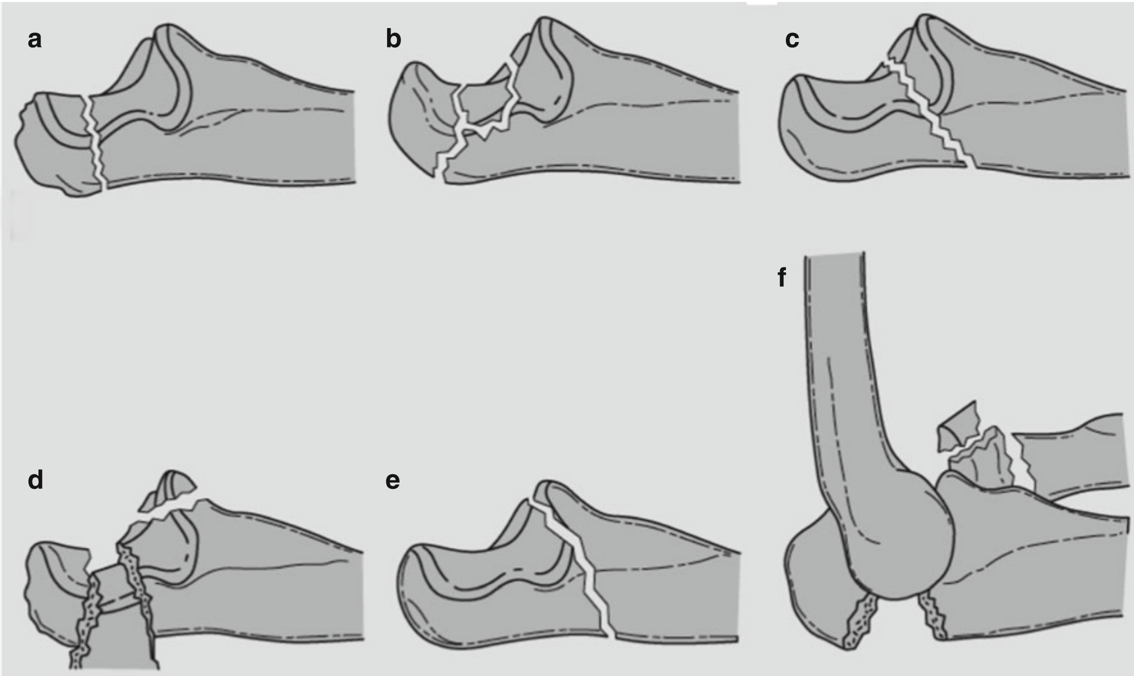

Fig. 10.1 Schatzker classification (Hölzl, Verheyden (2008) Diagnostik und Klassifikation Der Ellenbogenverletzungen, Isolierte Olecranonfrakturen. Der Unfallchirurg 111:727–734)

of the distal part of the olecranon. Schatzker type F fractures are unstable displaced fractures and represent a fracture-dislocation of the elbow joint.

Another classification system according to the AO (Arbeitsgemeinschaft für Osteosynthesefragen) takes the proximal radius and proximal ulna fractures as one group of lesions into account. These fractures are classified as belonging to region "21", "2" standing for the second long bone region (lower arm), "1" standing for the proximal part of it. Type A fractures are extraarticular, type B are intraarticular fractures concerning the articular surface of either the radius or the ulna, and type C are intra-articular fractures involving both bones.

A third classification system is the Mayo classification according to Morrey (Fig. 10.2). Olecranon fractures are divided into three types, with subtypes taking the degree of comminution into account. Mayo type I fractures are undisplaced fractures and may be subdivided into type A, noncomminuted fractures, and type B, comminuted fractures. Type II fractures are stable displaced fractures, and may be noncomminuted (type IIA) or comminuted (Type IIB). Type III are fracture dislocations.

10.5 Treatment

10.5.1 Conservative Treatment

Nondisplaced olecranon fractures may potentially be managed by maintaining the elbow in a semi-flexed position (to 90° of flexion) with a cast for 7–10 days. Follow-up radiographs at 1, 2, and 4 weeks after trauma are recommended to assess for displacement. After 1 week of immobilization, protected range of motion should be performed. Restrictions on active resisted elbow extension and weight bearing should be maintained for 6–8 weeks.

10.5.2 Operative Treatment

Displaced fractures require surgical intervention. Several different methods of internal fixation have been described. The fracture pattern plays a role in determining the fixation that is selected. Tension band wiring, intramedullary screw fixation, plate osteosynthesis, and fragment excision have been described.

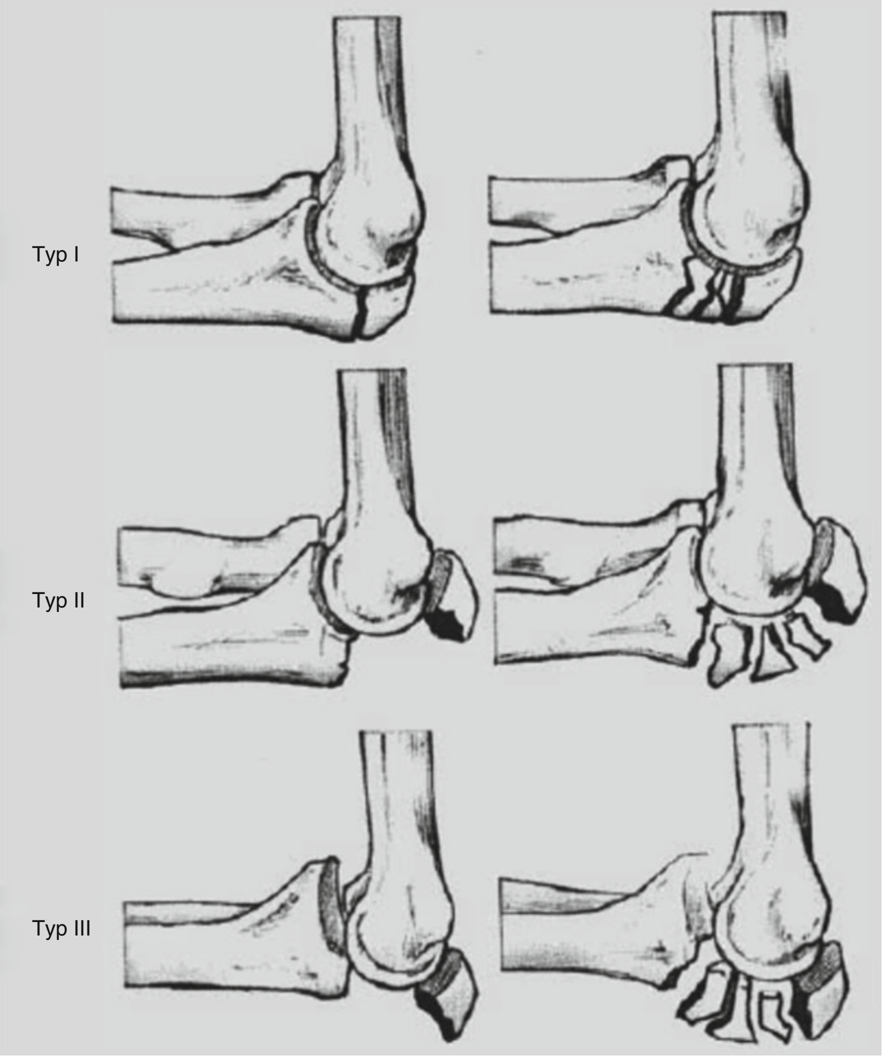

Fig. 10.2 Mayo classification

The aim of internal fixation is anatomic and permanent reduction of the articular surface, in order to mobilize the elbow as soon as possible and to prevent post-traumatic arthrosis.

10.5.2.1 Tension Band Wiring

Tension band wiring is widely used as treatment for most olecranon fracture types. The indication for tension band wiring are simple transverse and oblique fractures without comminution (Schatzker type A and C, Mayo type IIA). The tension band technique converts the extensor force of the triceps into a dynamic compression force across the fracture. After reduction, the fragments are temporarily fixed with two parallel 1.6-mm Kirschner wires drilled from the tip of the olecranon through the anterior cortex at the base of the coronoid. An additional lag screw is inserted as a first step in oblique fractures to obtain uniform compression. For insertion of the cerclage wire, a transverse hole is drilled distal to the fracture. The 1.0-mm wire is introduced under the triceps and the two Kirschner wires and then through the distal transverse hole. Two tensioning loops are used and tightened simultaneously and the twists laid down flat on the bone. The Kirschner wires are pulled back slightly, cut obliquely, and bent into a sharp loop. The hooks are impacted into the tip of the olecranon over the tension band wire. Alternatively to the Kirschner wires, an intramedullary screw with a tension band construct could be used (Fig. 10.3).

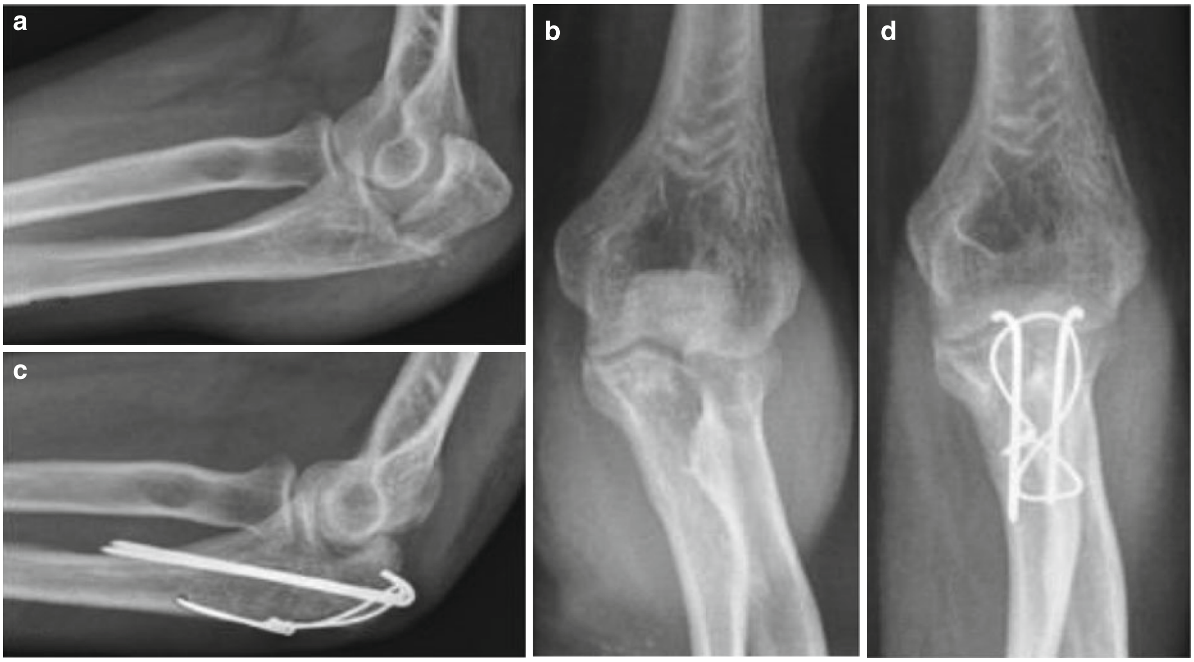

Fig. 10.3 X-ray of tension band wiring: (**a**) preoperative true lateral; (**b**) preoperative anterior-posterior; (**c**) postoperative true lateral; (**d**) postoperative anterior-posterior

10.5.2.2 Plate Osteosynthesis

Comminuted fractures of the olecranon (Schatzker type B, D, E, F and Mayo type IIB and III), especially those involving the coronoid process and those associated with trans-olecranon fracture dislocation, require plate osteosynthesis. In these fracture types, tension band wiring cannot provide enough stability to allow early postoperative motion. Tension band wiring may also lead to collapse of the comminuted fragments with shortening of the articular surface of the olecranon and incongruity of the joint. There are many different plating systems. Contouring the proximal end of the plate around the tip of the olecranon allows for orthogonal fixation with a longer intramedullary screw drilled through the most proximal hole. Recently, anatomic precontoured locking plates specifically designed for the olecranon have been introduced. These plates facilitate the placement of a long intramedullary screw. Locking plates enable a good anchorage in osteoporotic bone. Over a dorsal longitudinal approach, the olecranon is exposed for plate osteosynthesis. The reduction is performed using bone clamps or Kirschner wires. The locking plate is initially secured to the bone with a 2-mm Kirschner wire placed down the ulna into the coronoid. Then, a 3.5-mm bicortical screw is placed in the slotted hole to secure the initial fixation. Two screws are placed proximally into the hard cortical bone of the posterior olecranon. Then the screw in the slotted hole is loosened slightly to allow for compression over the fracture site. Care is taken to avoid overcompression, which would narrow the olecranon-to-coronoid distance. After the compression is applied, the slotted screw is retightened. Additional screws are placed through the locking holes in the plate (Fig. 10.4).

10.5.3 Complications

The most commonly reported complications of olecranon fractures are symptoms related to hardware. Kirschner wire migration occurs in 15 % of cases. In up to 66 % of fractures hardware removal is required. Other complications include loss of motion, ulnar nerve symptoms, infections, and pseudarthrosis. Loss of the terminal 10° of extension is particularly common and appears to be related to immobilization.

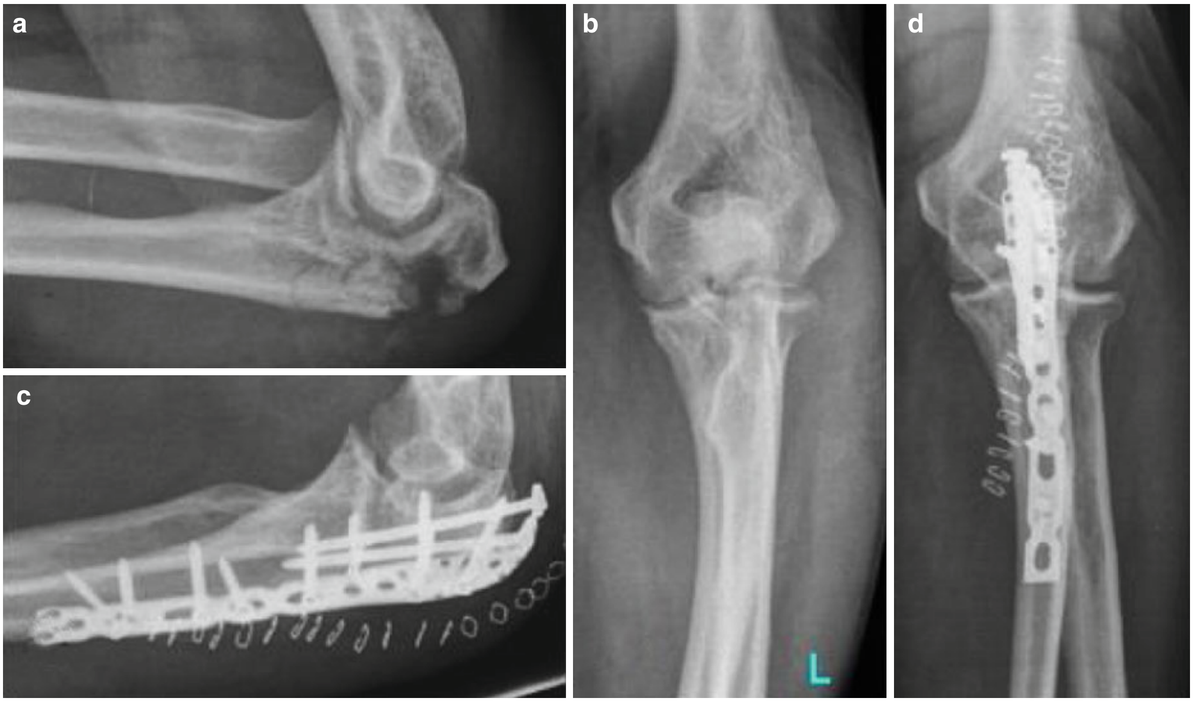

Fig. 10.4 X-ray of locking compression plating: (**a**) preoperative true lateral; (**b**) preoperative anterior-posterior; (**c**) postoperative true lateral; (**d**): postoperative anterior-posterior

Conclusion

Olecranon fractures are common injuries. The goal of olecranon fracture fixation is to provide adequate fixation, allow early motion, prevent stiffness, and avoid articular incongruity at the fracture site. With appropriate treatment, the patients have good to excellent long-term outcomes with only rare adverse events. Tension band wiring can be used in simple fractures of the olecranon. Plate osteosynthesis is particularly indicated in comminuted fractures and fracture dislocations.

11 Radial Head Fractures

Klaus J. Burkhart, Pol M. Rommens, and Lars Peter Müller

11.1 Introduction

Radial head fractures are the most common elbow fractures, accounting for 20–30 %. Typically, the fractures evolve from a fall on the outstretched hand with the elbow extended and the forearm in pronation. The role of the radial head as an important stabilizer of the elbow joint has been recognized in the last decade. Sixty percent of the axial load transmitted through the elbow is conducted through the radial head. Furthermore, the radial head is an important stabilizer against valgus stresses. While the medial collateral ligament (MCL) is the primary stabilizer against valgus stress, the role of the radial head emerges when the MCL is torn. These findings have led to a change in treatment recommendations.

11.2 Diagnosis

Patients present with a typical history. Pain and swelling is found over the lateral aspect of the elbow joint as the radial head is palpated. The distal radioulnar joint must be examined closely to exclude an interosseous membrane tear, the so-called Essex-Lopresti lesion. Flexion and extension may be limited due to hemarthrosis. Forearm rotation is usually sustained but may be limited by a mechanical block caused by a displaced radial head fragment. The medial elbow joint space is carefully palpated to exclude an injury of the MCL. Furthermore, elbow stability is tested if possible. The assessment of ligamentous injuries is important, as these influence the treatment significantly. It is well known that comminuted radial head fractures are especially associated with a high percentage of capsuloligamentous injuries.

Lateral and anteroposterior (a.p.) radiographs are performed. In case of significant loss of extension caused be hemarthrosis, two a.p. pictures may be needed: one of the humerus and one of the proximal forearm. The radiocapitellar view is helpful to evaluate radial head fractures. As plain radiographs often underestimate the number of fragments and degree of displacement, a computed tomography (CT) scan is useful to assess fragment size, number, and displacement. If there is any evidence for an injury of the interosseous membrane, bilateral a.p. radiographs of the wrist should be performed to determine the ulnar variance.

11.3 Classification

The most common classification is the Mason classification, which was later modified by Johnston (Fig. 11.1):

Type I	Not or minimally displaced two-part fracture (<2 mm)
Type II	Displaced two-part fracture (>2 mm)
Type III	Fractures with more than two fragments
Type IV	All fractures associated with elbow dislocation

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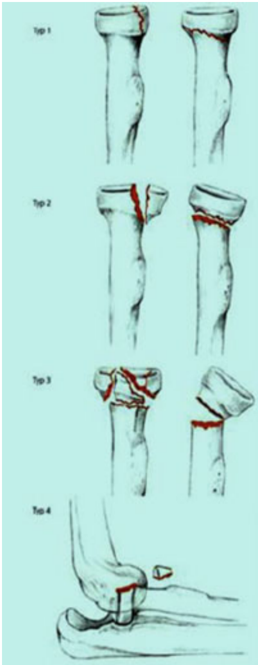


Fig. 11.1 Mason classification modified by Johnston

Another classification was developed by Hotchkiss, aiming to deduce a direct treatment recommendation according to the fracture type:

Type I	Not or minimally displaced fracture (<2 mm) of the head or neck No mechanical block Displacement less than 2 mm or marginal lip fracture
Type II	Displaced fracture (>2 mm) of the head or neck Mechanical block Without severe comminution (technically possible to repair by ORIF)
Type III	Severely comminuted fractures Judged not repairable by ORIF on basis of radiological or intraoperative appearance Usually requires excision for movement

The problem with Hotchkiss' classification is division between type II and III fractures. The border between type II and III is set differently among surgeons depending on their experience, fracture morphology and bone quality, available implants, and patient expectations. Therefore, this classification has not established itself in the current literature. The AO classification did not gain recognition because of its complexity and the lack of treatment recommendations.

In addition to the above-mentioned characteristics of radial head fractures, the treatment is strongly influenced by the associated injuries. The most common were summarized by Ring et al.:

1. Fracture of the radial head with posterior dislocation of the elbow
2. Fracture of the radial head with MCL rupture or capitellar fracture
3. Terrible triad injuries (radial head and coronoid fracture and MCL rupture)
4. Posterior transolecranon fracture dislocation (posterior Monteggia-like lesion)
5. Fracture of the radial head and interosseous ligament rupture (Essex-Lopresti)

11.4 Treatment

11.4.1 Conservative Treatment

Mason type-I fractures are treated conservatively. The injured arm is immobilized with a sling or cast for a few days. Afterwards, early active exercises are initiated. Good results can be expected in 85–95 % of the patients with a Mason I fracture. If normal range of motion does not return, a mechanical block must be excluded. A mechanical block caused by a displaced fragment is an indication for arthroscopic excision. Late excision of loose bodies does not affect the outcome. Diagnosis can be done by infiltrating local anesthetic in the elbow joint to allow for more aggressive passive forearm rotation.

11.4.2 Operative Treatment

11.4.2.1 Mason II

The treatment of choice of Mason type-II fractures is open reduction and internal fixation. Fractures of the radial head should be stabilized with either cortical screws (1.2–2.0 mm) or resorbable pins. Attention must be paid to the safe zone. The safe zone is the nonarticular part of the radial head that does not come into contact with the sigmoid notch of the proximal ulna during forearm rotation. With the forearm in neutral position, the safe zone is centered 10° anterior to the lateral side of the radial head. When the screws need to be placed outside the safe zone, they should be countersunk beneath the articular surface. Alternatively, headless compression screws can be used to avoid soft tissue irritation and interference during forearm rotation. Radial neck fractures can either be stabilized by crossed screws or, especially in case of metaphyseal defects, by plates. Plates should be placed in the safe zone, too. Low-profile plates should be used to avoid soft tissue irritation, especially of the annular ligament. Screws inserted in the radial head should not penetrate the contralateral cartilage because the screw tip would then come to lie within the proximal radioulnar joint and may there damage the cartilage. As a significant amount of the radial head's blood supply is running through the periosteum, extensive detachment during ORIF should be avoided. If the fragment is not amenable to refixation, fragment resection can be performed for fragments smaller than 25 % of the radial head's surface. Good results can be expected from ORIF of Mason II fractures.

11.4.2.2 Mason III + IV

The optimal treatment of comminuted radial head fractures is still a matter of discussion. The following options exist:

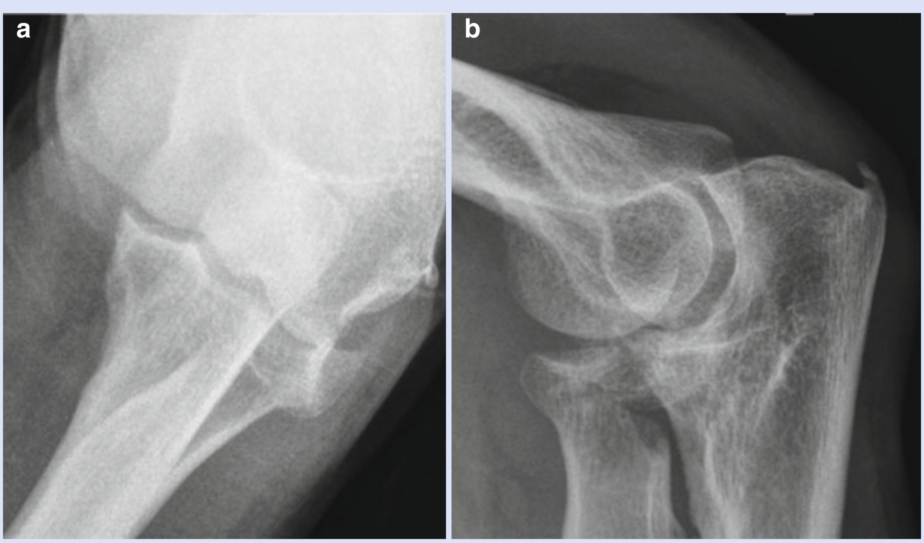
Open Reduction and Internal Fixation

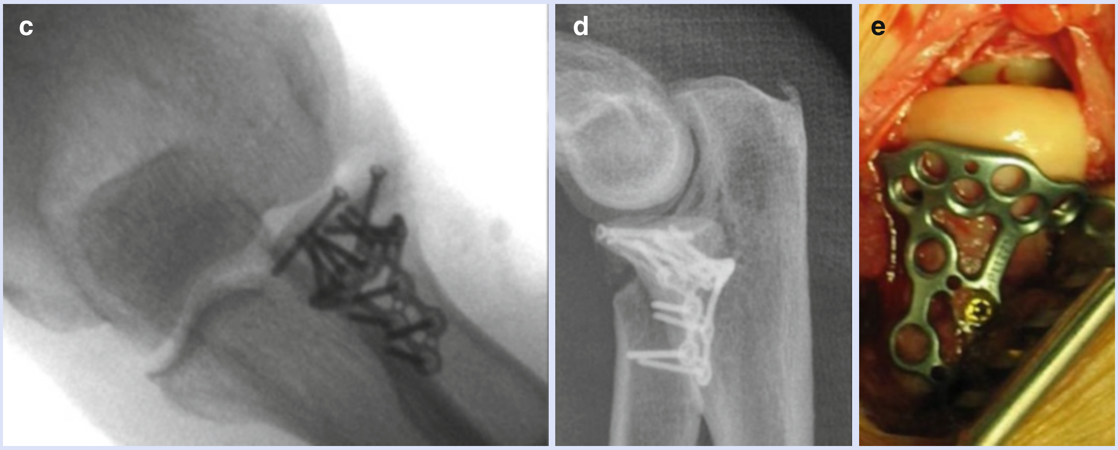
As the important role of the radial head as stabilizer of the elbow joint has been recognized, the interest in preserving and repairing the radial head has steadily increased. Open reduction and internal fixation of radial head fractures is recommended whenever it is possible to achieve an anatomic reduction and stabile fixation. After exposure, the fragments are carefully reduced with respect to the periosteum. The intact radial head fragment acts as a scaffold for the displaced fragments. If there is an additional neck fracture, the head fragments should be reduced and fixed first. Thereafter, the reconstructed head is correctly fixed to the neck with plate and screws. Metaphyseal defects can be filled with cancellous bone from the capitellum or olecranon. False fixation of the head to the neck may lead to limited ROM.

Not all radial head fractures can be restored with ORIF. There is no evidence of which radial head fractures are still amenable to ORIF and which ones are not. Ring suggested that radial head fractures with more than three fragments should not be repaired since he observed a high complication rate and poor clinical results in these patients. This was because unstable fracture fixation ORIF led to radial head necrosis, nonunion, and secondary loss of fixation. However, because the possibilities of ORIF have significantly improved, special locking plates have been developed, especially for the maintenance of radial head fractures. In our own biomechanical study, we found that these low-profile locking plates provide greater stability than conventional plates. In our opinion, these implants will extend the indications for ORIF of radial head fractures.

Case 1

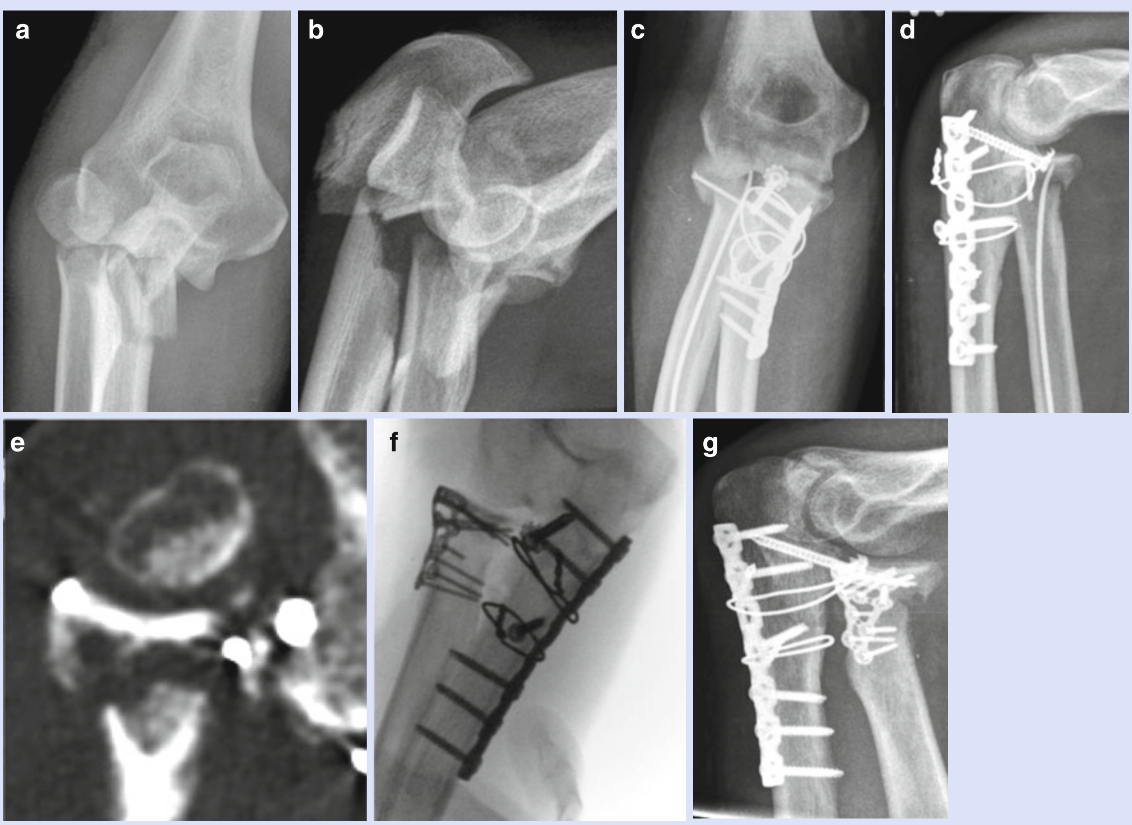
A 59-year-old male patient had a Mason III fracture with a severely dislocated fragment (**a**, **b**). After reconstruction of the radial head with two free screws, the head was fixed to the neck with a locking radial head buttress plate (Medartis, Switzerland) (**c**, **d**). This locking plate is placed beneath the radial head's articular surface. The intraoperative situs is shown in (**e**) (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)





Case 2

A 35-year-old male patient suffered a fracture dislocation of his right elbow (**a**, **b**). While the ulna healed, the proximal radius did not unite because of insufficient stability (**c–e**). When the patient was introduced to our department, he suffered from painful motion caused by the intra-articular lying Prévot nail with intraarticular penetration. The nail was removed and a plate osteosynthesis was performed with a locking radial head rim plate (Medartis) together with a cancellous bone graft from the capitellum (**f**, **g**) (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



Radial Head Resection

In severely comminuted radial head fractures, ORIF may technically not be possible. In these patients, resection of the radial head is a treatment option. This should only be considered in case of isolated comminuted radial head fractures. But comminuted radial head fractures usually are associated with capsuloligamentous injuries. These capsuloligamentous injuries are not accommodated sufficiently with resection of the radial head alone. Instability will be the result, ending up in a painful elbow and wrist. Fluoroscopic varus, valgus, and axial stress examination should be performed carefully after radial head resection. If there is any doubt of stability, metallic radial head replacement should be performed.

Radial head replacement may be superior to radial head resection, even in isolated comminuted radial head fractures. As 60 % of the axial loads are transmitted through the radiocapitellar joint in the inact elbow, the ulnohumeral joint has to bear all the loads after radial head resection. As a consequence, a high percentage of patients show radiographic evidence of osteoarthrosis. These findings are consistent with different biomechanical studies that reported altered kinematics and decreased elbow stability after radial head resection compared with intact, repaired, and replaced radial head. Therefore, radial head replacement may be superior to radial head resection even in isolated comminuted radial head fractures.

Prosthetic Replacement

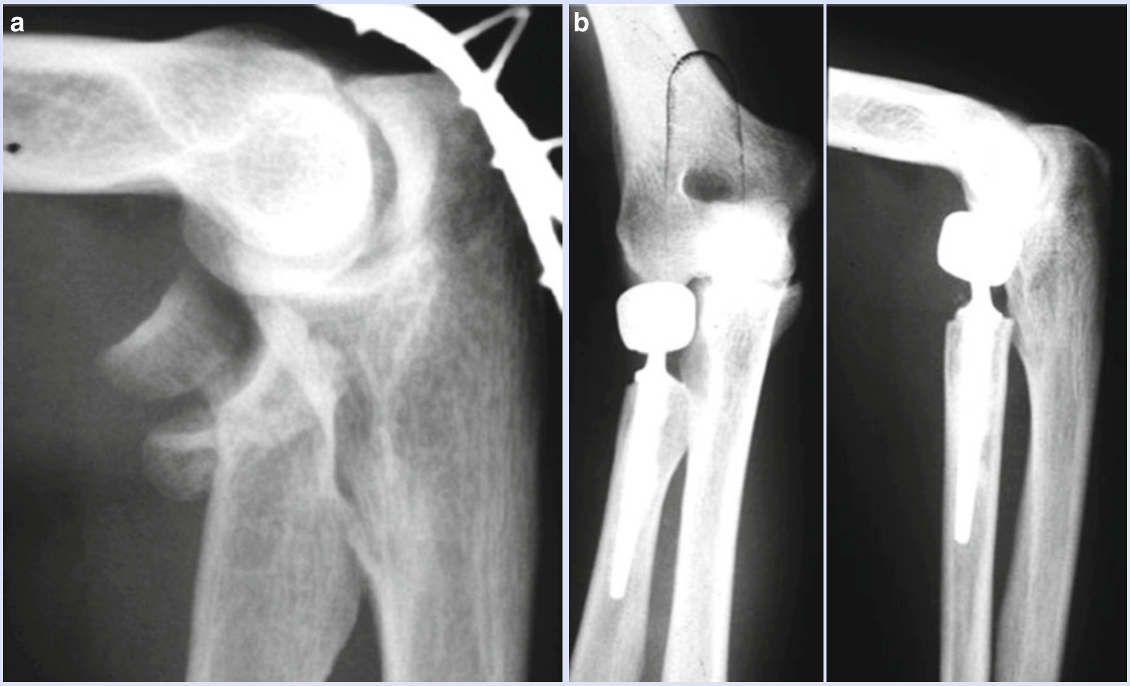
Metallic prosthetic replacement is considered the treatment of choice for the irreconstructible radial head fracture. A variety of different metallic implants are available. Current concepts comprise monopolar versus bipolar and cemented versus cementless designs. Radial head arthroplasty has proven to restore elbow stability for monopolar as well as bipolar metal implants. It has therefore superseded radial head resection as the treatment of choice for irreconstructible radial head fractures. In many studies, encouraging short-term results have been reported for all implants, but there still exists a lack of information concerning long-term results. Studies comparing the different designs are not available yet.

Implantation is demanding. There are some aspects that need to be addressed carefully to assure good clinical results. The most important points are the choice of the right implant size and implantation height. Several biomechanical studies have been performed to investigate this issue. Different sizes and orientations of radial head prostheses were found to essentially alter kinematics and load transmission of the elbow and wrist. This goal is difficult to achieve and is especially complicated by instability resulting from rupture of the MCL or interosseous membrane. Another problem is the fact that the radial head morphology is complex and is not yet perfectly imitated by currently available implants. The lesser sigmoid notch has been validated as a reference point for correct implantation of radial head prosthesis. Overstuffing of the elbow joint may lead to prosthesis dislocation and premature capitellar degeneration. After implantation, the full range of motion is assessed and the radiocapitellar contact is judged by the surgeon. Furthermore, the medial ulnohumeral joint space should be checked fluoroscopically for parallelism as well as distal radioulnar alignment and ulnar variance.

Radiocapitellar hemiarthroplasty is an option in case of concomitant capitellar cartilage damage. Radiocapitellar hemiarthroplasty is also possible in premature radiocapitellar osteoarthrosis after implantation of a radial head prosthesis.

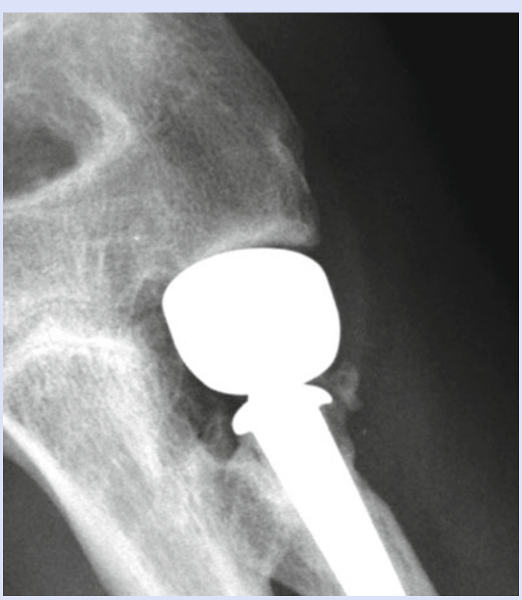
Case 3

Patient with an irreconstructible radial fracture (**a**) was treated with radial head arthroplasty (Tornier, France) (**b**) (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



Case 4

Capitellar erosion resulting from overstuffing of a radial head prosthesis (Tornier) (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



Treatment in the Setting of Associated Injuries

Fracture of the Radial Head with MCL Rupture and/or Capitellar Fracture

The radial head needs to be repaired or replaced. The LCL can be addressed through the same approach. The MCL usually does not need to be fixed, only in cases of persistent instability after ORIF or replacement. In some cases, a hinged external fixation must be performed additionally.

Terrible Triad Injuries (Radial Head and Coronoid Fracture and MCL Rupture)

Stable fixation or replacement of the radial head is required. Coronoid fractures larger than 10–30 % of the coronoid height should be fixed.

Transolecranon Fracture Dislocation and Monteggia-Like Lesions

The ulna fracture must be fixed first. Exact reduction is required to avoid alterations of the proximal radioulnar and radiocapitellar joint, which may lead to chronic instability.

Fracture of the Radial Head and Interosseous Ligament Rupture (Essex-Lopresti)

ORIF of the radial head should be performed whenever possible. If stable reconstruction is not possible, the radial head needs to be replaced. Major attention has to be paid to correct implant size and position as mentioned earlier.

11.4.3 Postoperative Rehabilitation

Active and active-assisted physiotherapy should be initiated as early as possible. Time of splinting should not exceed 2 weeks. However, exercises should begin early postoperatively. Varus and valgus stresses as well as resistive exercises should be omitted for 6 weeks. Forearm rotation should be performed in 90° of elbow flexion to protect the collateral ligaments. During extension exercises, the LCL is protected in pronation, the MCL in supination.

11.4.4 Complications

Comminuted radial head fractures carry a high potential for complications. Besides the above-mentioned specific complications of ORIF, radial head resection, and replacement, complications occur regardless of treatment. The most common is elbow stiffness. Furthermore osteoarthritis, heterotopic ossifications, and posterior interosseous nerve irritation occur.

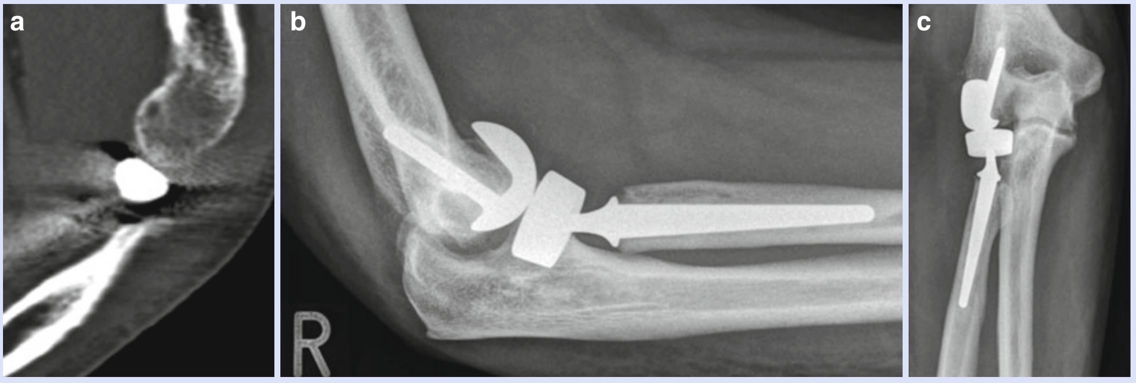
Conclusion

Radial head fractures are the most common elbow fractures. Nondisplaced fractures usually occur in isolation; displaced fractures come along with a high percentage of ligamentous injuries and concomitant elbow fractures such as the coronoid, capitellum, and proximal ulna.

Mason I fractures can be treated conservatively. Mason II fractures are handled by ORIF. Both lead to good results. Comminuted radial head fractures remain problematic. As these come with a high percentage of concomitant fractures and capsuloligamentous injuries, which need to be known, a concise clinical evaluation of the elbow joint is required. A stable elbow joint needs to be restored, either by ORIF or metallic prosthetic replacement of the radial head. As the radial head is an important stabilizer of the elbow joint – especially in the context of concomitant ligamentous injuries – its resection may lead to pain, limited range of motion, and instability. Radial head resection should not be performed in the acute fracture situation anymore. The treatment of choice should be ORIF with special locking radial head plates, regardless of the number of fragments, as long as a stable fracture situation can be achieved. If this is not possible, prosthetic replacement should be performed. Associated injuries need to be adequately addressed to achieve good clinical results. Prognosis is very good for simple Mason I and II fractures and deteriorates with increasing fracture types, radial head comminution, and associated injuries.

Case 5

Patient with progressive pain caused by osteoarthritis after radial head arthroplasty (**a**) was converted to radiocapitellar hemiarthroplasty (Tornier, France) (**b**) (© Klaus Burkhart, Lars Müller, Köln; Pol Rommens, Mainz)



12 Forearm Shaft Fractures

Hans-Jörg Oestern

12.1 Epidemiology

The incidence of radius and ulna shaft fractures out of all fractures of the forearm is 5 %, 19 % proximal radius and ulna (radial head and olecranon) and 76 % are distal radius fractures. The average annual incidence is 91 cases per 100,000 males and 196 cases per 100,000 females.

12.2 Etiology

The most common cause of diaphyseal fractures of the radius and ulna is a fall from standing height (35 %), followed by a direct blow (30 %), sport injuries (8 %), road traffic accidents involving vehicle occupants (4 %), road traffic accidents involving pedestrians (2 %), and a small number resulting from a fall from greater height or other miscellaneous reasons. The majority of fractures (60 %) were Association for the study of Osteosynthesis (AO) type A, that is, simple fractures of the ulna, radius, or both bones; 39 % were of B type and around 2 % were the more complex C type fractures [1].

12.3 Anatomy

Unique demands are made upon the forearm, which must serve the dual purpose of a rotational joint and a bony structure between the elbow and hand. The radius is curved in two planes, which allows for overriding of the ulna without restriction of pronation. Active forearm rotation is produced primarily by four muscles, two originating and inserting in the forearm (supinator and pronator quadratus) and two that cross the elbow joint (ponator teres, biceps). The forearm musculature is commonly considered as three separate compartments based on fascial divisons and nerve supply: the volar or flexor compartment innervated by the median and ulnar nerves, the dorsal or extensor compartment innervated by the posterior interosseous nerve, and the mobile wad of Henry (the brachioradialis and the extensor carpi radialis longus and brevis) innervated by the radial nerve. The divisions between the compartments delineate safe intervals for operative exposure. Anatomical studies suggest that the fascial divisions between these compartments are sufficiently pliant that fascial release of one compartment usually decompresses the remaining two.

12.4 Approaches

12.4.1 Ulna (Fig. 12.1)

The skin incision is on a line between the olecranon and ulnar styloid process. The incision falls in the plane between the medial and lateral posterior cutaneous nerves of the forearm. The dorsal cutaneous branch of the ulnar nerve crosses the extreme distal end of the ulna, running from volar to dorsal, and care must be taken to avoid injuring its branches. The posterior apex of the ulnar shaft defines the plane between the extensor carpi ulnaris innervated by radial nerve and the flexor carpi ulnaris innervated by ulnar nerve.

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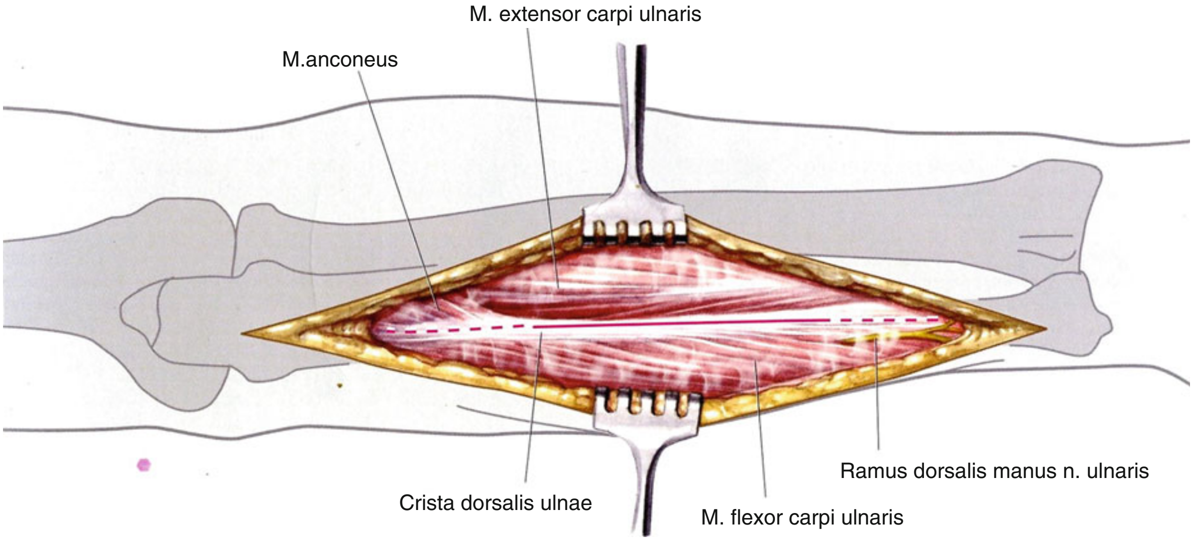


Fig. 12.1 Approach to the ulna. The skin incision is performed 5-mm volar or dorsal of the palpable edge of the ulna on a line between the olecranon and styloid process of the ulna. Between m. extensor and flexor carpi ulnaris a direct approach is made to the bone. Proximally, the anconeus m. must be detached. Care must be taken with the dorsalis manus branch of the ulnar nerve

Proximally, the ulna is exposed by detaching the anconeus. The ulnar nerve and artery lie underneath the flexor carpi ulnaris on top of the flexor digitorum profundus and are easily avoided, provided that elevation of the flexor carpi ulnaris is performed close to the bone and does not stray into its substance [2].

12.4.2 Radius

12.4.2.1 Thompson Approach (Fig. 12.2a–d)

The radial shaft can be exposed through either a dorsal or volar approach. The dorsal approach is commonly referred to by the eponym Thompson, the surgeon who popularized the approach [2].

The skin incision is a line between the lateral epicondyle and dorsal middle of the radius (Lister's tubercle). The elbow is slightly flexed and pronated. The fascia is divided at the radial border of extensor digitorum communis and further preparation is in the interval between this muscle and the extensor carpi radialis brevis. Distally, the abductor pollicis longus and extensor pollicis brevis emerge from between the mobile wad and dorsal compartment musculature in the distal half of the forearm. The fascia are incised at the proximal and distal border of these muscles. The bone is exposed by mobilization and retraction of both crossing muscles. The exposure of the proximal part of the radius requires identification and mobilization of the posterior interosseous nerve, as this nerve may lie almost adjacent to the bone at this level and could potentially be trapped beneath the plate. The posterior interosseous nerve emerges from beneath the superficial and deep heads of the supinator muscle, approximately 1 cm proximal to the distal limit of this muscle. It can be identified at this point and then dissected free from the muscle, preserving its muscular branches. After sufficient proximal mobilization of the nerve, exposure of the radial shaft can be performed by rotating the radius into full supination and detaching the insertion of the supinator from the anterior aspect of the radius [2].

12.4.3 Anterior or Henry Exposure

Exposure of the anterior surface of the radius is both safer and more extensile than a dorsal exposure (Fig. 12.3a–d) [3]. A straight longitudinal incision along a line between the lateral margin of the biceps tendon at the elbow and the radial styloid process at the wrist will afford access to the plane between the mobile wad and the flexor musculature of the forearm. This incision falls roughly between brachial cutaneous nerves. The deep fascia is incised adjacent to the medial border of the brachioradialis and a plane is developed between this radial nerve-innervated muscle and the median nerve-innervated flexor carpi radialis and pronator teres muscles. Dissection is initiated distally and proceeds proximally following the course of the radial artery. Arterial branches to the brachioradialis and the recurrent radial artery arising near the elbow are ligated and the radial artery is mobilized and retracted medially with the flexor carpi radialis

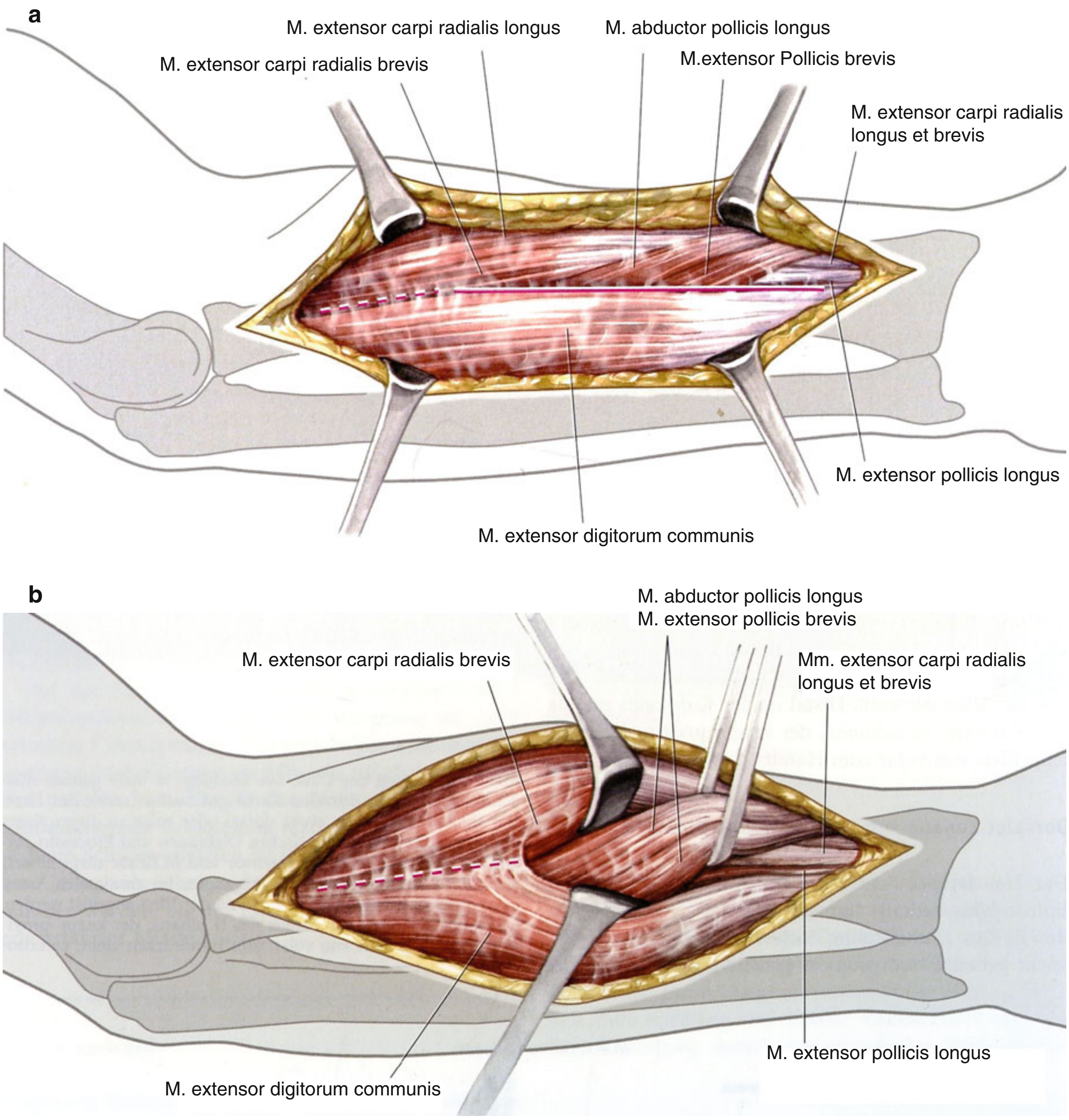
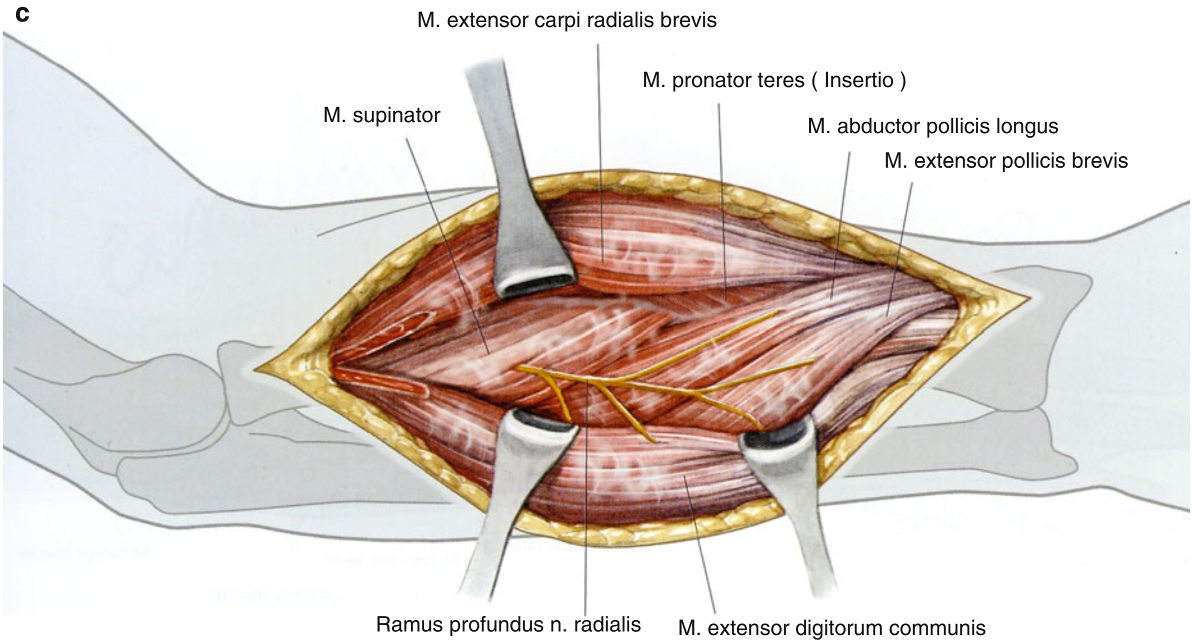


Fig. 12.2 Dorsal approach to the mid- and dorsal part of the radius. The skin incision is on a line between the radial epicondyle and Lister's tubercle. Incision of the fascia is made on the radial border of the extensor digitorum communis muscle and between this muscle and the extensor carpi radialis brevis muscle in the direct approach to the radius (**a**). Under distraction of both these muscles, awareness of the abductor pollicis longus and the extensor pollicis brevis muscle is required. The fascia is incised at the proximal and distal border. Both muscles are mobilized and tied with a loop (**b**). For proximal fractures, the supinator m. Must be identified (**c**). Three transverse fingers away from the radial head, the radial nerve can be felt, which is prepared by splitting of the supinator m (**d**)



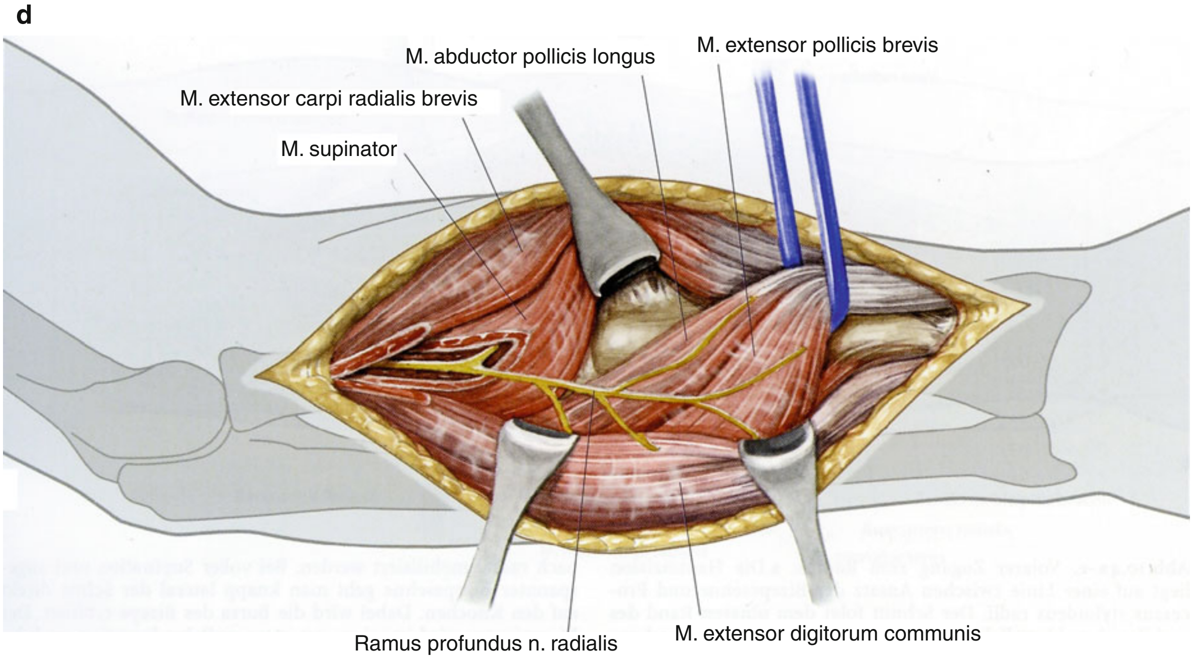


Fig. 12.2 (continued)

muscle. The superficial radial nerve is encountered on the undersurface of the brachioradialis and remains lateral with this muscle [2].

Deep dissection is initiated proximally where the biceps tendon is followed towards its insertion on the bicipital tuberosity of the radius. Full supination of the forearm displaces the posterior interosseous nerve laterally and brings the insertion of the supinator muscle anterior. The insertion of the supinator muscle is identified by the deepening of the muscular plane along the lateral aspect of the biceps tendon. Here, one may encounter a bursa between the biceps tendon and the supinator, which further facilitates this dissection. The posterior interosseous nerve (Fig. 12.4) remains well protected within the substance of the supinator muscle during elevation of its insertion from the radius, provided that excessive lateral traction is not applied.

The insertion of the pronator teres must be detached and the body of the flexor digitorum superficialis elevated in order to expose the midportion of the radius. This is performed by pronating the arm in order to bring the lateral limit of these structures into view.

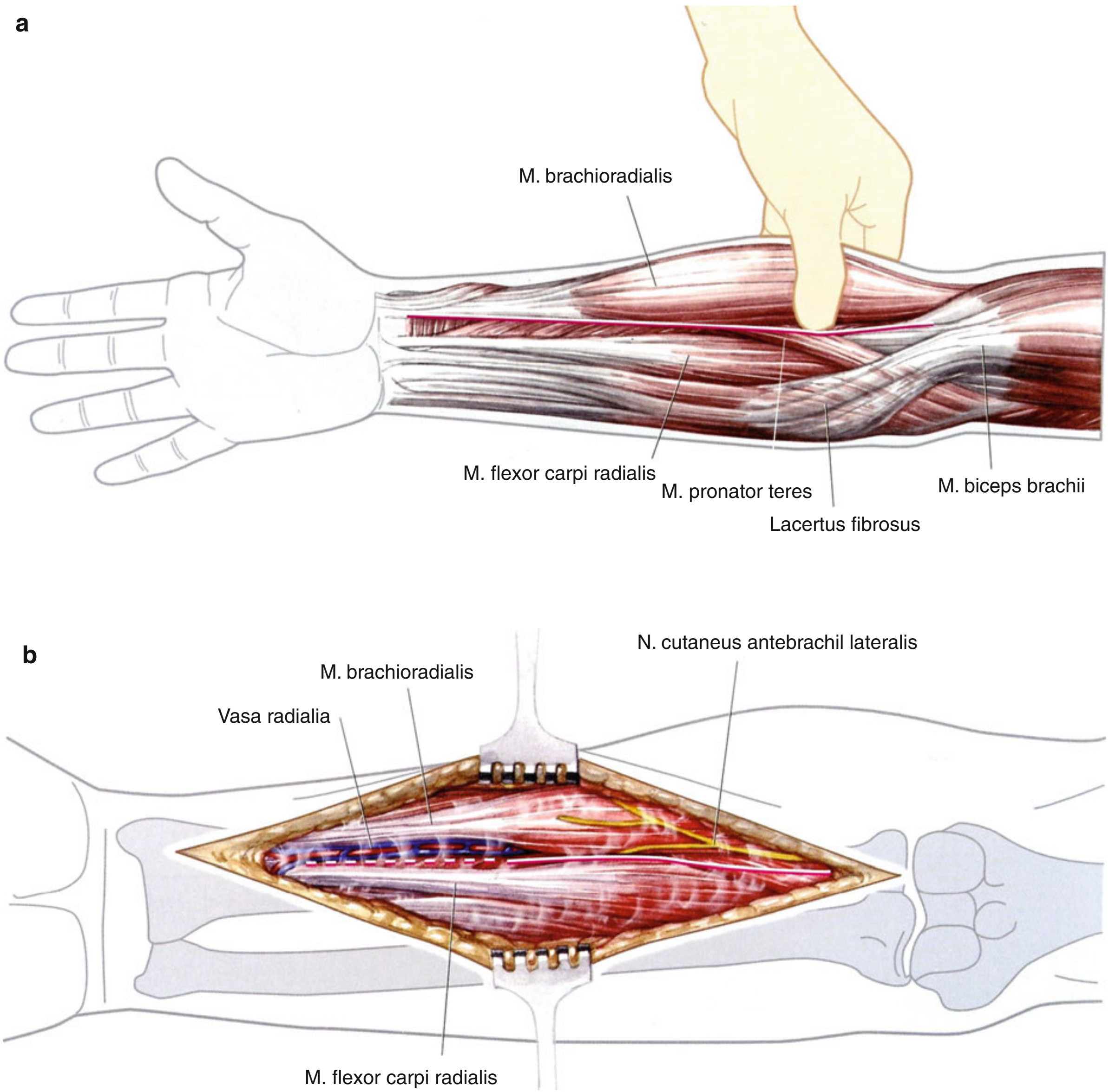


Fig. 12.3 Volar approach to the radius. The skin incision is on a line between the insertion of the biceps tendon and the radial styloid process (**a**). Thereafter, the incision follows the ulnar border of the brachioradialis muscle and the flexor carpi radialis m. Care must be taken of the cutaneous antebrachii n. on the brachioradialis m. (**b**). Mobilization of the of the brachioradial m. towards radial after ligation of braches of the radial artery. Underneath the brachioradialis m., the superficial branch of the radial n. can be seen. Incision of the fascia is at the lateral border of the biceps tendon. Preparation between the biceps tendon and flexor carpi radialis on one side and brachioradialis m. on the other side. Ligation of the radial recurrens artery. In full supination, approach to the radius at lateral border of the biceps tendon. The supinator m. is detached at the radial insertion (**c**). Under pronation, the proximal part of the radius is prepared. The deep branch of the radial nerve is dorsal and lateral. For the approach to the mid- and distal part of the radius, the pronator teres m. and the flexor digit. superfic. m. are detached in full supination (**d**)

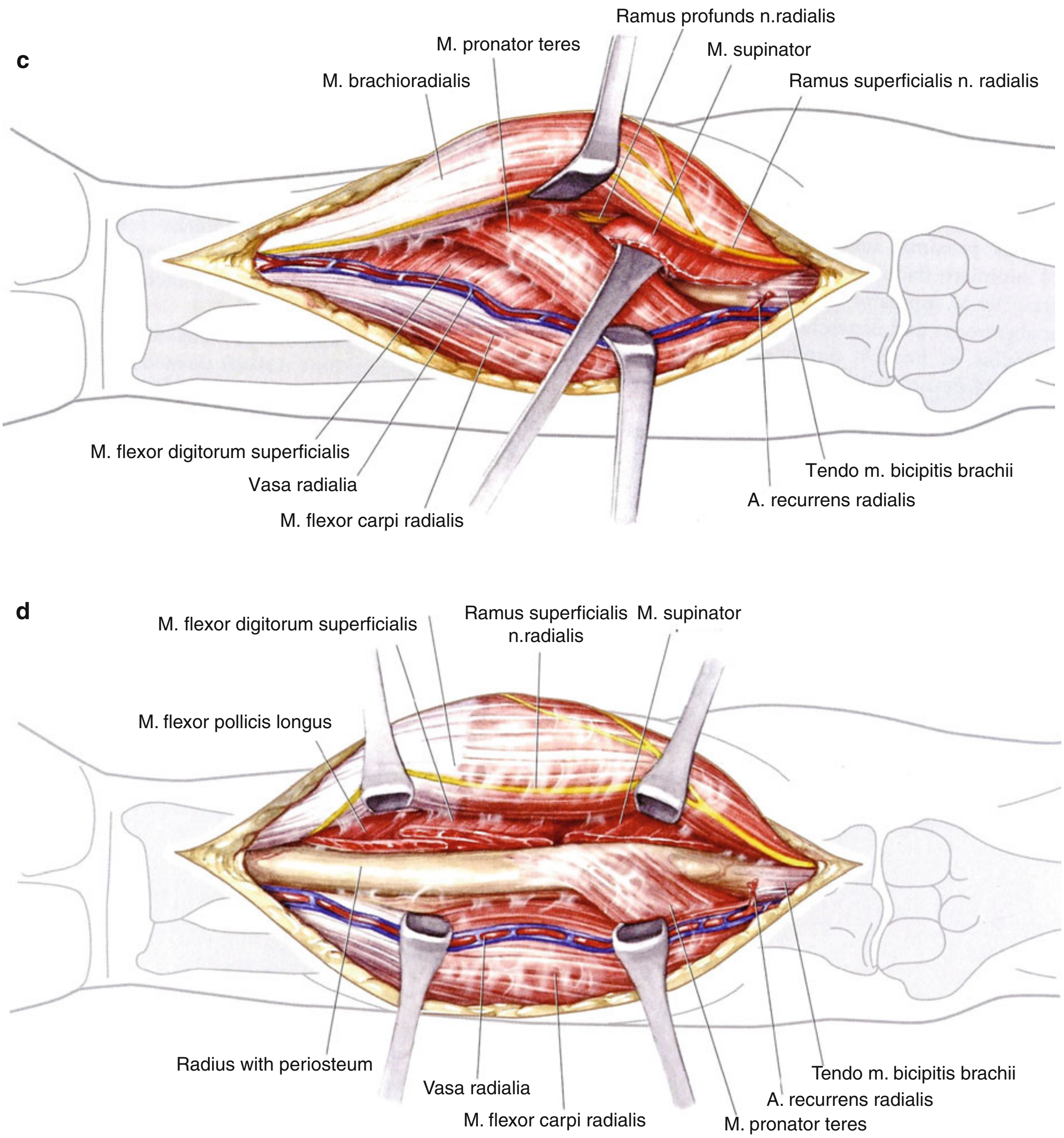


Fig. 12.3 (continued)

12.5 Surgical Technique

Conservative treatment of forearm shaft fractures results in a poor functional outcome, with the exception of the rare case of undisplaced fractures. Therefore, nearly all forearm shaft fractures are indications for plate osteosynthesis and early functional treatment (Fig. 12.5). Tissue of the forearm tends to scar. Therefore, special care of soft tissue is needed: adequate skin incision, indirect reduction when necessary,

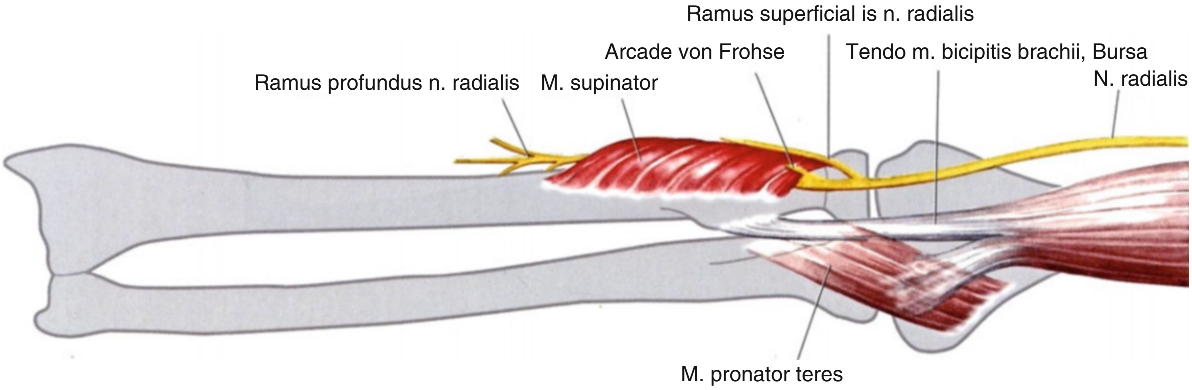


Fig. 12.4 Position of the radial nerve

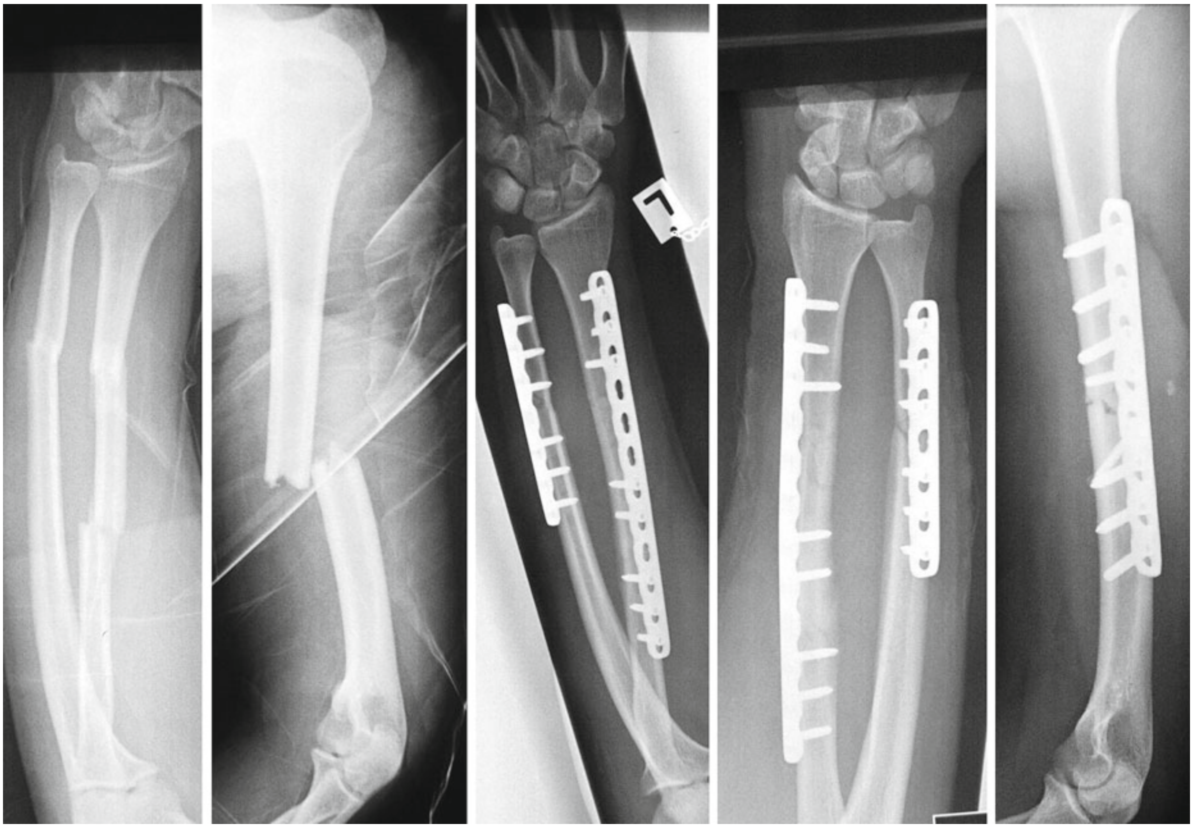


Fig. 12.5 Serial fractures of the humerus, radius and ulna. Plate fixation of all fractured bones in one surgery. X-rays preoperatively and 6 weeks postoperatively

only 2–3 mm dissection of the periosteum, no direct pressure, and denudation by Hohmann retractors. Reduction starts in complete forearm shaft fractures with the least severe fracture in most instances: the ulna.

12.5.1 Reduction Technique

Transverse or short oblique fractures of the radius or ulna are mostly easy to reduce and should always be

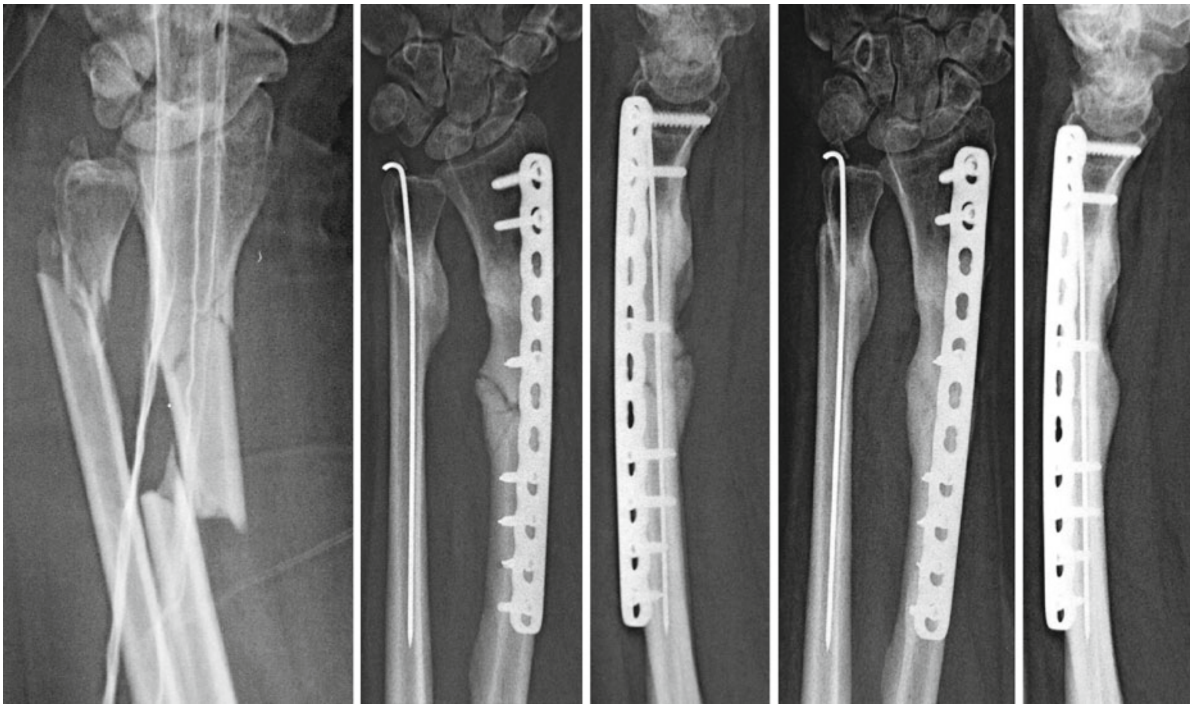


Fig. 12.6 Multiple-injured patient. Segmental fracture of the radius and distal ulna fracture. X-rays 6 weeks and 1 year after accident

approached first. Reduction can usually be obtained by manipulating either fragment with fine-pointed reduction forceps. An alternative is to loosely fix the plate (minimum seven–hole, 3.5-mm limited contact-dynamic compression plate (LC-DCP) or LCP (less contact plate)) with one screw to the main fragment and to subsequently reduce the opposite fragment to the plate. Attention must be paid to any rotational malalignment. We fix simpler fractures initially with a plate and two screws and then approach the other bone with the more complex fracture pattern. Once both bones have been stabilized, pronation and supination are controlled. As soon as there are one or more intermediate fragments, the indirect reduction technique should be applied. Again, usually a long 8- to 10-hole plate is fixed to one main fragment with one screw only. Close to the opposite end of the plate, a 3.5-mm cortical screw is introduced into the other main fragment. With the help of a small lamina spreader, which is placed between that screw head and the free end of the plate, distraction of the fracture can be obtained, thus allowing the fragments to fall into place or to be gently manipulated without stripping their soft tissue attachments. The plate can then be fixed to the bone as a bridge plate, not interfering with the comminuted area at all. If, on the other hand, some larger fragments can be fitted back anatomically, they should be fixed by small interfragmentary lag screws, always from the main fragment, while axial compression may be added by eccentric screw placement. Today, the implant of choice for both forearm bones is the 3.5-mm LC-DCP or LCP (Fig. 12.6).

Autogenous bone grafts are only suggested if there is a substantial bony defect or if the vitality of the fracture zone appears questionable (i.e., too extensive damage or exposure). Bone grafts should not, however, be placed close to the interosseous membrane.

12.6 Galeazzi Fracture

12.6.1 Definition

This uncommon injury involves a fracture of the shaft of the radius at the junction of the middle and distal thirds in association with dislocation at the distal radioulnar joint [4].

12.6.2 Biomechanics

Currently, most favour a mechanism that includes axial loading of a hyperpronated forearm [5]. As displacement continues, the force may be transmitted via the interosseous membrane to the ulna, causing dislocation of the ulnar head and tearing of the triangular fibrocartilage complex, with resultant loss of its stabilizing influence on the distal radioulnar joint [5].

12.6.3 Radiographic Findings

These include:

1. A short oblique fracture of the radius with dorsal angulation as seen on the lateral radiograph
2. Shortening of the radius in relationship to the distal ulna on the anteroposterior radiograph
3. Fracture of the ulnar styloid at its base
4. Widening of the distal radioulnar joint space on the anteroposterior radiograph
5. Dorsal displacement of the ulna relative to the radius, seen best on a true lateral radiograph

The last three findings, if associated with radial shortening of more than 5 mm, are suggestive of traumatic disruption of the distal radioulnar joint [6].

12.6.4 Treatment

Inability to reduce the distal radioulnar joint or its redislocation was originally thought to be an infrequent occurrence. If the distal radioulnar joint is reducible but unstable with forearm rotation, there exist several treatment alternatives. In those cases associated with a fracture of the ulnar styloid at its base, open reduction and internal fixation of the styloid fracture is recommended, using either Kirschner wires in conjunction with a tension band or a small screw.

Should there be no associated ulnar styloid fracture, the distal ulna may be transfixed to the radius using Kirschner wires with the forearm in 40° of supination. In this case, an above-elbow cast is recommended for 6 weeks. The Kirschner wires are removed after 6 weeks [7].

Almost all irreducible distal radioulnar joint dislocations reported to date have been caused by tendon entrapment. The tendons implicated include the extensor carpi ulnaris [8], extensor digiti minimi, or both [9]. In these cases, operative exposure of the distal radioulnar joint is recommended. Through a dorsal approach, the entrapped tendon is elevated, the joint reduced, and, if possible, the triangular fibrocartilage repaired. The forearm should be immobilized in an above-elbow cast for 6 weeks in 40° of supination [6].

12.6.5 Complications

Malunion results most frequently from a combination of the following: (1) inability to restore the radial bow and (2) alteration of location of the maximum radial bow. It has been shown that in patients with a malunion of the radius, there was a change in the magnitude of the radial bow and in its location. Schemitsch and Richards [10] showed that this usually resulted in forearm rotation of less than 80 % of normal with the difference being statistically significant.

12.7 Monteggia Lesion

12.7.1 Definition

In 1814, Giovanni Battista Monteggia described an injury of the forearm in which the proximal ulna fractured and the radial head was dislocated. Since then, this injury has been eponymously associated with his name [11, 12].

12.7.2 Classification

The internationally accepted classification of the Monteggia lesion was devised by Jose Luis Bado [13]. He classified this lesion into four distinct types. Percentages mentioned are those from his series.

Type I: Anterior dislocation of the radial head. Fracture of the ulnar diaphysis at any level with anterior angulation (60 %).

Type II: Posterior or posterolateral dislocation of the radial head. Fracture of the ulnar diaphysis with posterior angulation (15 %).

Type III: Lateral or anterolateral dislocation of the radial head. Fracture of the ulnar metaphysis (20 %).

Type IV: Anterior dislocation of the radial head. Fracture of the proximal third of the radius. Fracture of the ulna at the same level (5 %).

12.7.3 Mechanism of Injury

The different types of Monteggia lesions reflect different mechanisms of injury.

12.7.4 Clinical Features

The feature common to all types of Monteggia injuries is the degree of pain about the elbow and a mechanical block to forearm rotation. Assessment of the patient's neurological status is of paramount importance. The posterior interosseous nerve is the nerve most frequently reported to be involved.

12.7.5 Radiological Features

A line through the radial shaft and head should intersect the capitellum for any position of the elbow [14].

12.7.6 Methods of Treatment

While it is accepted that pediatric lesions often only require manipulative reduction and a cast, it is also agreed that adult lesions are an entirely different entity and the results of manipulative reduction prove unsatisfactory. The method of choice is careful reduction of the ulna and fixation by a plate. If the ulna is in a correct length, the radial head is reduced in most cases. Rarely, the radial head must be exposed and open reduced.

12.7.7 After Treatment

A cast is not necessary and movement is started immediately.

12.8 Essex-Lopresti Lesion

12.8.1 Description

Radial head fractures are associated with injury to the interosseous membrane and disruption of the distal radioulnar joint [15].

12.8.2 Mechanism of Injury

Most of these injuries are caused by a fall onto the outstretched hand with the forearm pronated. In this position, it is possible to disrupt the distal radioulnar joint as well as the interosseous membrane. In addition, the degree of radiocapitellar contact is high in pronation [16]. The axial force is therefore transmitted to the radial head, which abuts against the capitellum leading to fracture of the radial head [15, 17–19]. With sufficient force, the fracture fragments are displaced, and because of the concomitant disruption of the distal radioulnar joint and interosseous membrane, the radius will have a tendency to migrate in a proximal direction.

12.8.3 Clinical Presentation

Symptoms and signs at the elbow are similar to those of radial head fractures. Any evidence of instability of the ulnar head or asymmetric prominence of the ulnar head should be suggestive of acute disruption of the distal radioulnar joint. In addition, alteration of the normal relationship between the radial and ulnar styloid processes (as compared to the normal side), restriction of ulnar deviation at the wrist, or swelling of the forearm are corroborative of distal radioulnar joint injury and suggestive of an unstable forearm with the potential for proximal radial migration.

12.8.4 Radiographic Examination

It is imperative that all cases of comminuted radial head fractures should have the wrist examined radiographically.

A posteroanterior projection and a zero-rotation lateral projection as described by Epner [20] are extremely helpful in accurate determination of any proximal radial migration. Corroborative evidence may be gained by similar views of the contralateral wrist, which will provide information regarding the patient's normal ulnar variance. The upper limit of proximal migration of the radius during normal rotation of the forearm has been shown by Morrey et al. [21] to be 2 mm.

12.8.5 Treatment

The goals of treatment include restoration of radial length and stabilization of the distal radioulnar joint. This will depend to a large degree on the type of radial head fracture. Stability of the distal radioulnar joint must be tested. If stable, then external immobilization in supination should be extended for 4 weeks. If the ulnar head is not stable after reduction, it may be pinned to the radius with the forearm in 40° of supination for a similar period of 4 weeks, after which the pin is removed and forearm rotation is commenced.

12.8.6 Complications

Complications associated with the Essex-Lopresti lesion can be divided into those resulting from the severe radial head fracture alone and those resulting from its excision and instability of the forearm articulation [22]. Among the most troublesome complications are proximal radial migration, restriction of forearm rotation, and wrist pain associated with considerable loss of grip strength. In addition, excision of the radial head may be associated with valgus instability of the elbow [19] and heterotopic bone formation. Failure to achieve accurate reduction and fixation of the radial head or an untreated fracture of the radial head can lead to both post-traumatic arthritis and stiffness of the elbow.

12.9 Complications [23]

12.9.1 Compartment Syndrome

12.9.1.1 Incidence

Gunshot fractures of the forearm are particularly prone to compartment syndrome. Moed and Fakouri [24] recorded a 15 % overall incidence among 60 gunshot fractures of the forearm. Comminuted and severely displaced fractures are commonly associated with compartment syndrome.

12.9.1.2 Treatment

Release of the volar compartment is achieved via an incision that begins proximal to the humeral epicondyles, crosses the antecubital fossa obliquely, releasing the lacertus fibrosis, and then takes either a straight course down the ulnar aspect of the forearm (e.g., McConnell's combined exposure of the ulnar and median nerves as described by Henry [3]) or a curvilinear course over the mobile wad. With either approach, the incision then returns to the midline and crosses the wrist crease, ending in the mid-palm and allowing release of the carpal tunnel and Guyon's canal [3, 25]. This fasciotomy can be accomplished as a part of Henry's anterior exposure of the radius during open reduction and internal fixation [3]. If the compartment syndrome has progressed to include median nerve weakness, Gelberman et al. [25, 26] suggest exploring and releasing the nerve where it dives beneath the pronator teres and flexor superficialis muscles. Following volar compartment release, dorsal pressures are measured, and if they are still elevated, the dorsal compartment is released via a midline longitudinal incision.

12.9.2 Infection

When infection occurs, its eradication is not necessarily dependent upon implant removal. In early cases, as long as all bone fragments and soft tissues are well vascularized, stable internal fixation will facilitate wound care and help maintain length and alignment, as well as range of motion and overall function, without hindering treatment of the infection. Following successful eradication of the infection (with organism-specific antibiotics, debridement, and irrigation), the wound can be drained and closed.

In delayed cases, if bone debridement results in a substantial gap, this can be temporary filled with antibiotic beads. Vacuum sealing may be necessary in severe infections. Autogenous cancellous bone graft from the iliac crest or other sites may be added at the time of secondary wound closure. Bone loss is also common in gunshot fractures; early cancellous bone grafting in conjunction with stable plate fixation has been found to be effective. On the other hand, an external fixator may be the implant of choice in cases of severe infection or gunshot wounds, followed by plate fixation, according to soft tissue and bone conditions after 1–2 weeks.

12.9.3 Nonunion

12.9.3.1 Hypertrophic

Recommendations include the use of 3.5-mm dynamic compression plates or LCP applied in the compression mode to appropriate transverse and oblique fractures. In general, fixation to a minimum of eight cortices (four bicortical screws) on either side of the fracture is requisite in most cases [27].

12.9.3.2 Atrophic

In cases with atrophic nonunion comminution or bone loss, 10- or 12-hole plates should be utilized in conjunction with immediate autogenous iliac crest cancellous bone grafting. The current rate of nonunion is less than 2 % when proper technique is utilized in compliant patients [28]. Patients with stable plate and screw fixation are mobilized almost immediately postoperatively. Nonunions are ascribed to technical errors such as the use of plates of inadequate length, inadequate reduction, and failure to bone graft comminuted fractures.

12.9.4 Malunion

Failure to restore the location and magnitude of the radial bow to within 4–5 % of that of the normal arm was associated with greater than 20 % loss of forearm rotation. Grip strength was also reduced in malunited fractures. Dependent on the complaints of the patient, correction osteotomy must be performed.

12.9.5 Synostosis

Recent documentation of the local and systemic risk factors for the development of synostosis (including high-energy traumatic injury with soft tissue damage, fracture comminution, dislocation of adjacent joints and/or wide displacement of fracture fragments, prolonged immobilization and associated head injury, multitrauma, or burns) has illustrated the numerous similarities between this entity and heterotopic ossification. Post-traumatic radioulnar synostosis is more common with fractures of the radius and ulna at the same level [29, 30] and delayed internal fixation [31]. It occurs more commonly in the proximal and mid-forearm than in the distal forearm [32, 33].

12.9.5.1 Treatment

Suggested treatment consists of resection of the synostosis with interposition of various materials intended to discourage recurrence (silastic, muscle, or fat) [33–35]. Resection is associated with a risk of damage to neurovascular structures, especially in the proximal third of the forearm [33]. The overall reported recurrence rate following resection is approximately 30 % [33]. Noting the similarities between post-traumatic radioulnar synostosis and heterotopic ossification, postoperative radiation treatments have been attempted with some success in preventing recurrence [36, 37]. To this end, nonsteroidal anti-inflammatory agents (such as indomethacin) and frequent, early range of motion exercises may also be useful [22].

The timing of surgery is critical. With regard to heterotopic ossification of the hip and elbow, delayed intervention is most commonly advised to allow for the maturation of the new bone in the hope that this will decrease recurrence rates. However, the accepted measures of bone maturity (serum alkaline phosphatase level, radiography, and bone scanning) are of limited reliability, and excessive delay can lead to contraction of soft tissues with resultant limitations in maximal recovery of range of motion and function.

The difficulties of successful treatment of synostosis emphasize the importance of preventing this complication. Surgeon-related risk factors include violation of the interosseous space either by surgical exposure [33, 38] or via a screw of excessive length [33, 39], and placement of bone graft on the interosseous membrane [33]. Proper, stable internal fixation with early motion should help limit the occurrence of synostosis to patients with substantial risk factors such as brain injury.

12.10 Refracture

The risk of refracture following plate removal is believed to result from a combination of incomplete healing and osteoporosis that occurs under a plate as a result of some combination of disruption of the vascular supply to the bone and stress shielding. Animal experiments suggest that refracture may occur because the screw holes diminish energy absorption by 50 %. Risk factors for refracture following plate removal include fracture comminution and inability to gain compression of fracture fragments [2, 40, 41].

It is recommended that forearm plates remain in place unless (1) they cause local symptoms (e.g., tenosynovitis) or (2) the patient is an athlete returning to high-energy activities, in which case the ends of the plates might be expected to act as stress risers and increase the risk of fracture. On the basis of the existing literature, the risk of refracture following plate removal can be expected to be minimal if fractures are fixed with 3.5-mm LC-DCP or LCP, the plates are not removed until at least 2 years following the original injury (perhaps longer in cases in which the fracture was comminuted), and patients are advised to avoid high-energy activities for at least 2–3 months. If both bones are fractured, sequential removal with a time interval can reduce the refracture rate. Exact preoperative X-rays in four planes and, if uncertainty regarding bone healing exists, a CT are necessary.

12.10.1 Treatment

Treatment entails reosteosynthesis, either with LCP or LC-DCP. Additional bone grafting might be necessary in some cases.

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13 Distal Radius Fractures

Hans-Jörg Oestern

13.1 Epidemiology

The incidence of distal radius fractures is approximately 0.7/1,000/Y people in males and 2.1/1,000/Y in females.

13.2 Anatomy

The articular surface of the distal radius is biconcave and triangular in shape with the apex of the triangle directed towards the styloid process, while the base represents the sigmoid notch for articulation with the ulnar head. The surface is divided into two hyaline cartilage-covered facets for articulation with the carpal scaphoid and lunate bones. The articular end of the radius slopes in an ulnar and palmar direction (Fig. 13.1). There are six dorsal compartments that are together with the convex dorsal aspect of the radius and are of extreme importance in surgical approaches. Eighty percent of axial load is transferred to the radius through the carpus. Rotation of the radius about the ulna is accompanied by a translational movement such that in supination the ulnar head is displaced anteriorly in the notch, whereas in pronation it moves dorsally. At the ulnar aspect of the lunate facet arises the triangular fibrocartilage, which extends onto the base of the ulnar styloid process, functioning as an important stabilizer of the distal radioulnar joint. It is situated between the ulnar head and carpal triquetrum. Its volar and dorsal margins are thickened, blending into the dorsal and volar radioulnar ligaments. The surfaces are biconcave and covered with hyaline cartilage.

Additional secondary stabilizers of the distal radioulnar joint include the interosseous membrane of the forearm, the pronator quadratus muscle, and the tendons and sheets of the extensor and flexor carpi ulnaris muscles.

13.3 Classification

The most complex and often used classification is that of the AO. Type A fractures are extraarticular, B are partial articular, and C are complete articular fractures. The A 1 fractures are extraarticular fractures of the ulna with an intact radius and they increase in severity from A 1.1 to A 1.3 [17] (Fig. 13.2).

The A 2 fractures are extraarticular, either undisplaced A 2.1, with dorsal tilt A 2.2 or with volar tilt A 2.3. Any extraarticular fractures with metaphyseal comminution falls into the A 3 group, with increasing comminution from A 3.1 to A 3.3, with A 3.3 fractures being those with comminution extending into the diaphysis. The A 3.2 fracture is the typical Colles' fracture with metaphyseal comminution.

The B type are partial articular. The B 1 fractures are sagittal fractures of the radius (B 1 is the styloid process fracture), B 2 are fractures of the dorsal rim, and B 3 affect the volar rim [17].

The C fractures are complete articular where the articular surface is fractured and totally separated from the metaphysis. C 2 fractures are simple articular with metaphyseal comminution, and C 3 fractures

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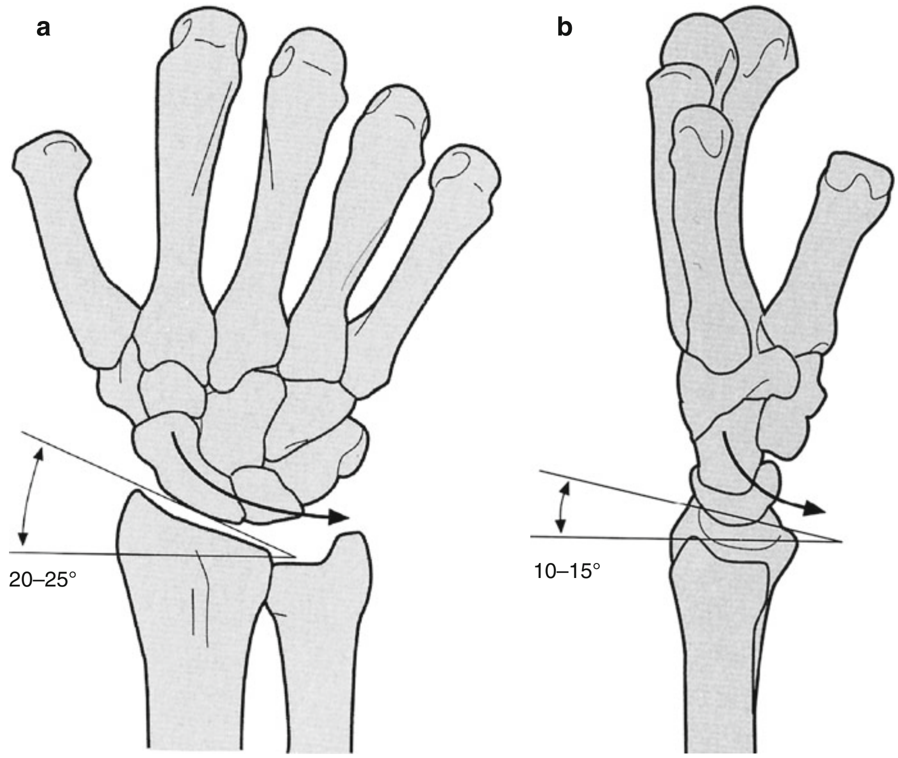

Fig. 13.1 The articular end of the radius slopes in an ulnar and palmar direction. The carpus will thus have a natural tendency to slide in an ulnar direction, resisted for the most part by the intracapsular and interosseous carpal ligaments arising from both the radius and the ulna

are the most complex, with multiple articular fracture lines and increasing metaphyseal comminution. Additionally, there are several classification systems only for intraarticular fractures. Melone described four possible parts: the radial shaft, the radial styloid, and the dorsal and volar portions of the lunate facet, which he termed the medial complex. Type 1 injuries are stable and type 2 occur when the radial styloid splits from the intact medial complex. Type 3 injuries are like type 2 but with a volar spike, which may damage the soft tissue. Type 4 injuries occur when, along with other features, the dorsal and volar parts of the medial complex are split. In 1993, Melone added a type 5, which he described as an explosion injury with severe articular comminution [15] (Fig. 13.3).

13.4 Mechanism of Injury

A fall on an extended hand is the classical cause of distal radius fractures. The force of the body weight is transmitted through the carpus directly to distal metaphysis, where the cortex is thinnest.

13.5 Diagnostic Features

Besides pain and swelling, the typical bayonet or fourchette position is often seen. There is a possibility of concomitant injuries such as scaphoid fractures, SL ligament lesions, and radial head fractures.

13.5.1 Radiology

Plain radiographs remain the mainstay in diagnostics. The posteroanterior view (PA) obtained in neutral variance as well as a lateral view with a beam that is inclined 20° will assess ulnar variance and effectively visualize the articular surface. A 45° pronated oblique view is helpful in that it profiles the dorsal ulnar cortex and lends insight into this biomechanically important region. Sometimes, improved fracture visualization through computed tomography is valuable (Fig. 13.4). A high number of fractures classified as extraarticular by standard radiographs are revealed to be intraarticular injuries. Special angles and lengths characterize the fracture pattern [7, 24].

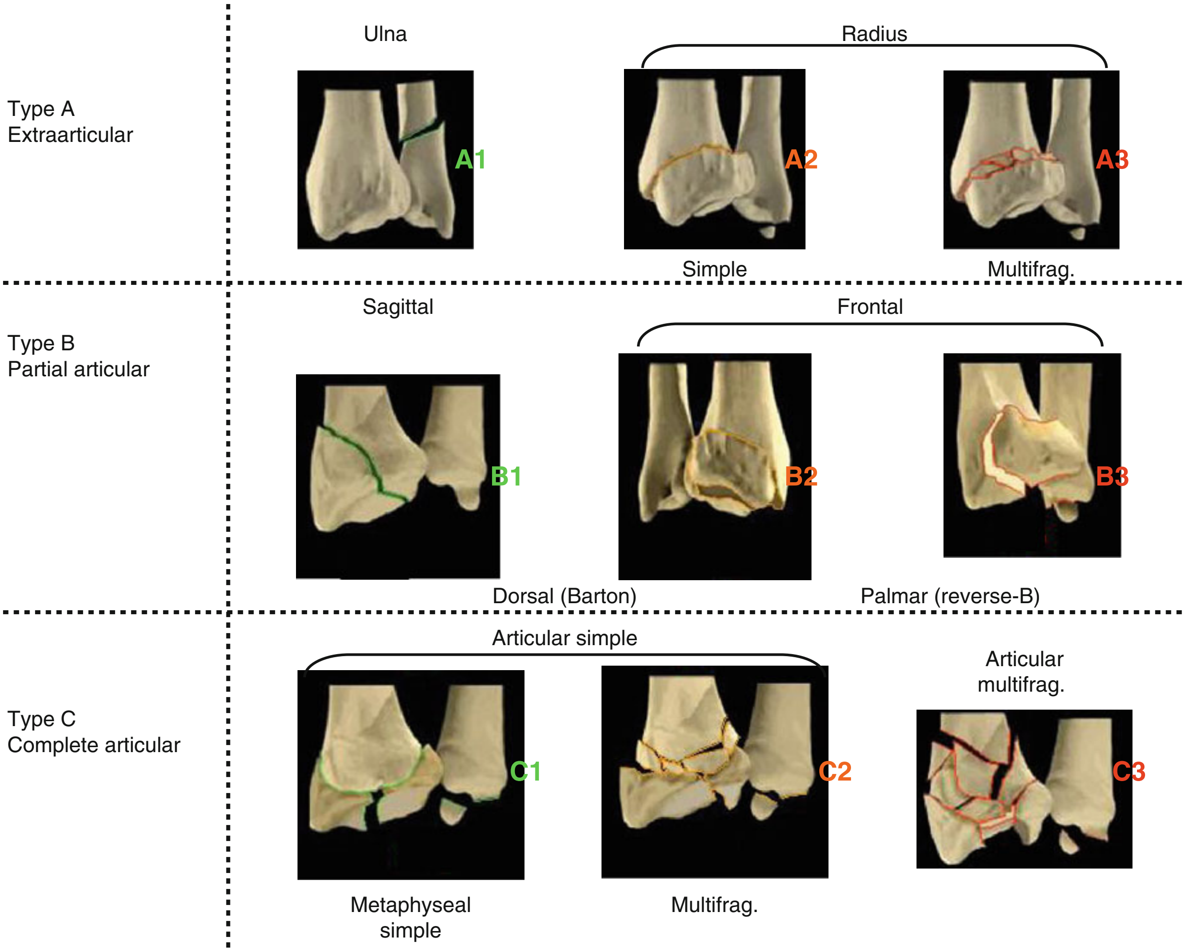

Fig. 13.2 AO classification of distal radius fractures

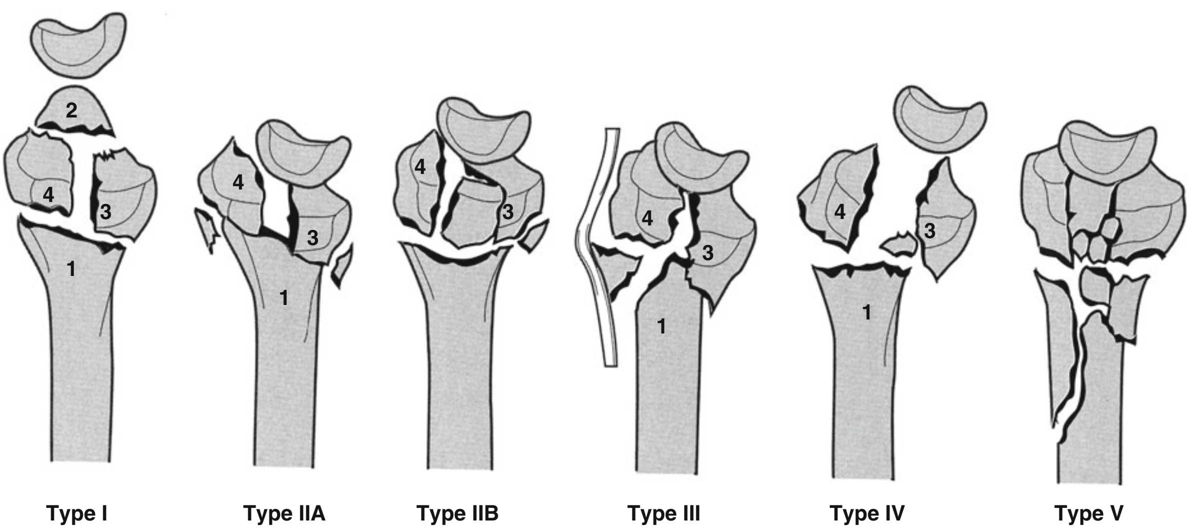

Fig. 13.3 Classification of intraarticular fractures according to Melone. 1 radial shaft, 2 radial styloid, 3 dorsal medial fragment, 4 palmar medial fragment. The medial fragments ande their strong ligamentous attachments with the proximal carpal bones and the ulnar styloid have been termed the "medial complex " by Melone

Fig. 13.4 CT gives information about step in the articular surface and SL lesion

13.5.1.1 Radial Length (Fig. 13.5a)

Radial length is measured on the a.p. radiograph. This measurement (in millimeters) represents the distance between a line drawn at the tip of the styloid radial process, perpendicular to the long axis of the radius with a second perpendicular line at the level of the distal articular surface of the ulnar head. The normal length is 10–12 mm.

13.5.1.2 Radial Slope

In the frontal view, the slope or inclination of the distal end of the radius is represented by the angle formed by a line drawn from the tip of the radial styloid process to the ulnar corner of the articular surface of the distal end of the radius and a line drawn perpendicular to the longitudinal axis of the radius. The average inclination is between 22° and 23° (Fig. 13.5b).

13.5.1.3 Palmar Inclination

To obtain the palmar inclination of the distal radius in the sagittal view, a line is drawn connecting the most distal point of the dorsal and volar cortical rims. The angle that this line creates with a line drawn perpendicular to the longitudinal axis of the radius reflects the palmar inclination. This angle has an average inclination between 10° and 12° (Fig. 13.5c).

13.5.1.4 Ulnar Variance

The vertical distance between a line parallel to the articular surface of the ulnar head and a line parallel to the proximal surface of the lunate facet of the distal radius has been referred to as the ulnar variance. The ulnar head and the medial corner of the radius are normally at the same level bilaterally.

With fracture displacement, the ulnar head will commonly be in a distal relationship (positive variance).

13.5.1.5 Radial Width, Shift

This width is the distance in mm from the most lateral tip of the radial styloid process to the longitudinal axis through the center of the radius on the a.p. radiograph.

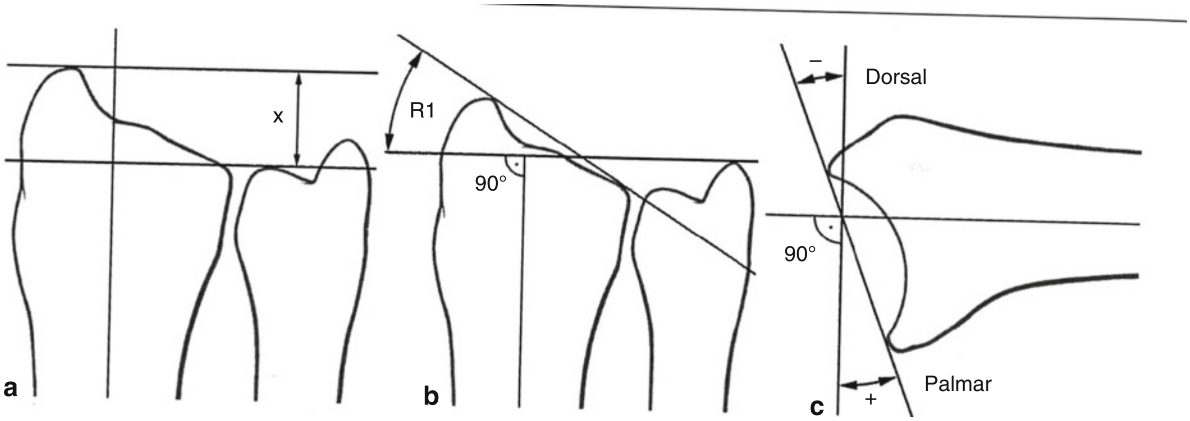

Fig. 13.5 The radial length (**a**) (*height*) averages in the frontal plane 11–12 mm in reference to the distal radioulnar joint 1. Line tangential to the top of the radial styloid and perpendicular to the long axis of the radius 2. Line perpendicular to the long axis of the radius and tangential to the ulnar head. The ulnar inclination (**b**) is measured from a coronal view as the angle between a line connecting the most distal points of the radial and rims of the articular surface and a perpendicular to the long axis of the radius. The palmar tilt or inclination (**c**) is measured from a sagittal view as the angle between a line connecting the most distal of the dorsal and palmar rims of the articular surface and perpendicular to the long axis of the radius

13.6 Conservative Treatment

While clinical practice guidelines are not able to recommend one form of treatment over another, there has been a rise in surgical treatment of distal radius fractures [10, 27].

13.6.1 Reduction

Many fractures are simply reduced by traction. Classically, dorsal bending fractures are reduced by applying longitudinal traction, palmar flexion, ulnar deviation, and pronation. Another reduction technique introduced the concept of multiplanar ligamentotaxis, in which longitudinal traction is combined with palmar translation. Palmar translation creates a moment force in which the capitate will rotate the lunate palmarily. This, in turn, will produce a rotatory force that can effectively tilt the distal radial fragment in a palmar direction. Radioulnar translation is advocated to realign the distal fragments with the radial shaft.

13.6.2 Immobilization

The immobilization technique by L. Böhler [4] is based on the concept of a three-point cast.

Displaced but intrinsically stable extraarticular dorsal bending fractures can be effectively maintained initially in a sugar tong splint followed by a below-elbow immobilization, provided care is taken to apply appropriate molding of the cast [22]. Cast immobilization carries with it concerns regarding restricted range of motion, muscle weakness, and long-term disability [19].

13.6.2.1 Duration of Immobilization

Most well-reduced extraarticular dorsal bending fractures will heal by 4–5 weeks postinjury.

13.6.3 X-Ray Control

After 48 h, 7 days, 14 days, and 28 days, X-ray controls are recommended for conservative treatment.

The reasons are to avoid malunion resulting from secondary displacement, either by a second reduction and conservative treatment or by changing the procedure from conservative to operative management.

13.7 Operative Technique

13.7.1 Indications and Contraindications of Operative Treatment

Because of a high degree of secondary displacement and malunion, sympathetic reflex dystrophy, and other complications after conservative treatment, a change to operative treatment of displaced distal radius fractures has happened (Table 13.1).

Table 13.1 The treatment of distal radius fractures has changed to internal fixation. The indication, the surgical approach (palmar, dorsal, combined palmar and dorsal) and the choice of implants must be based on patients history, pathomechanics of the fracture, fracture pattern (x-ray), bone quality and the demands of the individual patient

A2	Angle stable plate	K-wire
A3	Angle stable plate	K-wire
B1	Screw Fixation	(Lag screw)
B2	Angle stable plate	
B3	Angle stable plate	
C1	Angle stable plate	
C2	Angle stable plate	
C3	Ext. Fix and K-wires, Angle stable plate	

Open reduction of articular fractures of the distal radius is indicated when intraarticular congruity of the fracture cannot be achieved by closed manipulation, joint distraction, or percutaneous reduction maneuvers in manually active patients with good bone quality and absence of preexisting wrist pathology. Open reduction and internal fixation is also indicated in open fractures and in fractures with associated carpal disruption and tendon or nerve injuries because immediate skeletal stability is a prerequisite for undisturbed soft tissue healing. Delayed open reduction may be indicated for secondary intraarticular displacement in a fracture that undergoes loss of reduction after a conservative trial with closed reduction and plaster fixation. Articular fractures in elderly inactive patients and those with massive osteoporosis indicate open reduction and fixation with angular stable plates. Contraindications, not related to the fracture itself, may include the general condition of the patient, associated diseases, and the presence of degenerative changes of the wrist joint prior to injury (e.g., nonunion of the scaphoid, Kienböck's disease, rheumatoid arthritis). Operative treatment might be contraindicated in unreliable, unmotivated, and noncooperative patients.

13.7.2 K-Wire Fixation

The method of Willenegger [26] is based originally on the description of Lambotte.

13.7.2.1 Reduction

A tourniquet should be applied if limited or formal open reduction becomes necessary. With the image intensifier properly draped, a classical closed manipulation with traction, palmar flexion, and ulnar deviation is performed. The quality of reduction is assessed under fluoroscopy, while traction is maintained by the surgeon and countertraction by the assistant. Alternatively, horizontal longitudinal traction can be applied using sterile finger traps with 2.5–5 kg weights and countertraction across the upper arm. This frees both the surgeon's hands for manipulation and pinning.

13.7.2.2 Surgical Technique

An open or closed procedure is possible. The advantage of the open procedure is the identification of superficial radial nerve by a 2 cm incision over the styloid process. After identification of the nerve and closed reduction, three 1.8mm K-wires are inserted via the tip of the styloid process into the distal fragment. The pins should cross in both planes. An additional forearm cast is necessary. Implant removal usually is performed after 6 weeks (Fig. 13.6).

13.7.2.3 Principles of Intrafocal Pinning and Surgical Technique

Traditionally, fractures of the distal end of the radius were fixed, after manual reduction, with pins drilled through the distal fragment and pinned into the proximal one. Quickly, because of the pins' flexibility, the distal fragment moves back until the pins bump into the inferior edge of the proximal fragment.

In the original method of intrafocal pinning, a smooth K-wire is inserted after a manual reduction, through a short skin incision, directly into the fracture line [12, 13] (Fig. 13.7). In this way, any subsequent tilt of the distal fragment is prevented. Secondary displacement is made impossible by the immediate contact of the distal fragment with the pins, which are working as an abutment, not as a resistance component. Additional cast immobilization is not necessary with this technique, allowing immediate rehabilitation and, therefore, better functional results [23]. A good fixation needs three pins, inserted at precise points. The first pin is pushed laterally between the tendons of the extensor carpi radialis and that of the extensor pollicis brevis; the second pin is inserted postero-laterally, close to Lister's tubercle, and, taking great care to avoid the extensor pollicis longus, the third is postero-medially set, passing between the extensor digitorum tendons and the extensor carpi ulnaris tendon. Clearly, this approach needs to avoid the tendons.

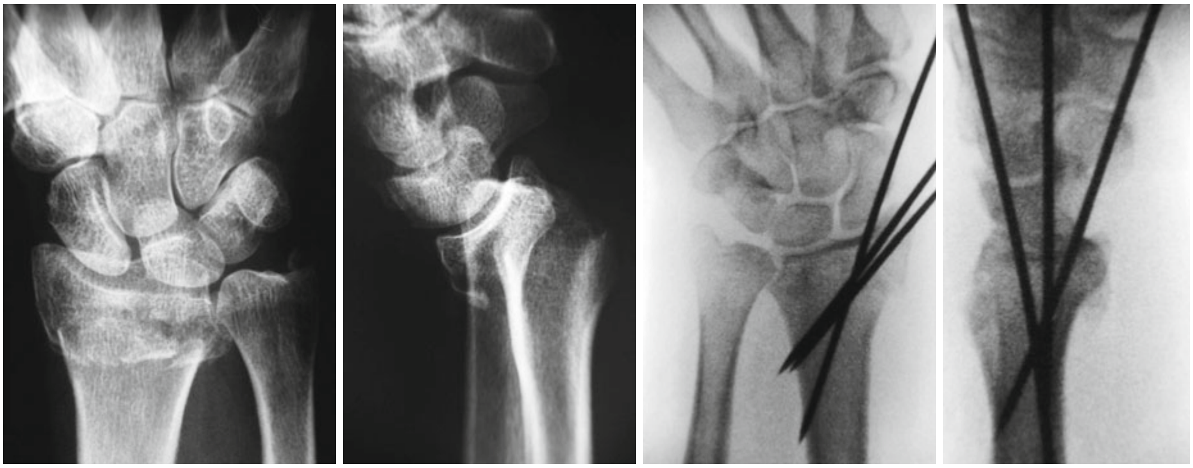

Fig. 13.6 A3 Fracture K-wire fixation. Crossing wires in both planes

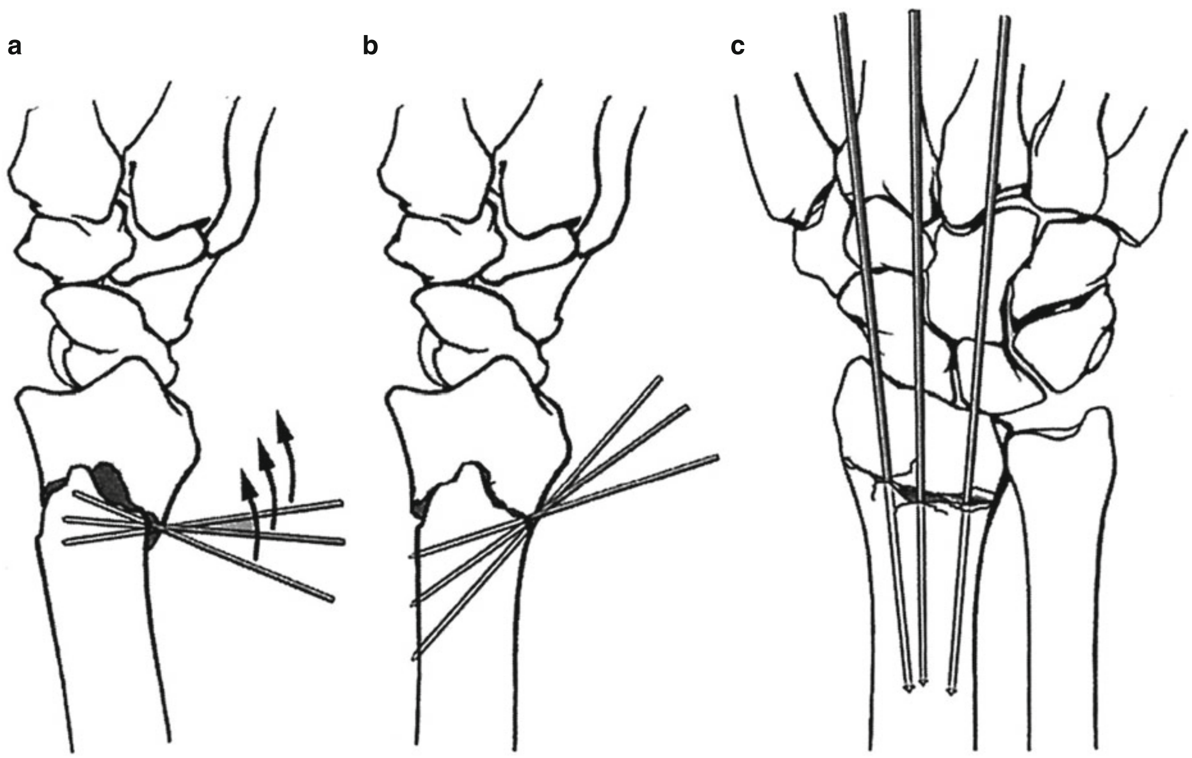

Fig. 13.7 Intrafocal pinning (Kapandji). This technique remains most effective in those unstable fractures without substantial volar comminution.3 pins (**a**) are placed into the fracture line, functioning to help reduce the fracture as well as to provide an internal splint, under reduction the pins (**b**) are directed approximately at a 45° angle to the long axis of the radius and driven to the intact proximal cortex.The pins (**c**) are located between ext carpi rad. and ext. pollicis brevis, between ext. pollicis longus and ext. indicis and between ext. digit. and ext carpi ulnaris tendons

13.7.3 External Fixator in C 3-Fractures

13.7.3.1 Reduction

Restoration of radial length, volar tilt, and articular congruity is assessed by closed reduction. If there is no metaphyseal comminution and reduction of the joint fragments is acceptable, a conventional percutaneous pinning of the fracture is carried out. If reduction of the "medial complex fragments" [8] is anatomic with no articular step-off, additional pinning from the radial styloid towards the sigmoid notch is performed using 1.5-mm Kirschner wires, with care not to enter the radio-ulnar joint. If a satisfactory reduction of the dorso-medial fragment cannot be achieved by radial deviation and palmar flexion [8], then a 2-cm-long skin incision is placed between the fourth and fifth dorsal compartments and, with a minimum of soft tissue dissection, an awl or periosteal elevator is introduced. Under fluoroscopy, the displaced fragment is reduced against the lunate and pinned transversely as described above. When the medial fragments are split into dorsal and volar components (four-part fracture) and the volar fragment is severely displaced, the limited open reduction through a volar approach is mandatory. This volar ulnar fragment cannot be reduced anatomically by closed manipulation or traction because of its tendency to rotate dorsally when tension is applied to the volar capsule. When the articular fracture shows a considerable degree of metaphyseal and even diaphyseal comminution, external fixation is the most reliable method of stabilization to prevent radial shortening. However, if radiocarpal and radio-ulnar congruity cannot be achieved with external fixation alone, a percutaneous or formal open reduction of the joint surface should be used, in combination with the external fixator [9]. Before applying the external fixator, the gross displacement of the fracture is reduced with a conventional closed manipulation, and the quality of reduction is assessed with the image intensifier.

13.7.3.2 Technique External Fixator

If satisfactory reduction is obtained with adequate correction of the radial inclination and radial length, as well as the volar tilt, a temporary percutaneous fixation of the radial styloid is performed. Then, two 2.5-mm half-threaded pins are inserted into the base and the shaft of the second metacarpal. The pins are inserted through small stab wounds, spreading the underlying soft tissues with a hemostat and using a protection guide. If the bone is osteoporotic, the pins may be inserted directly; otherwise, predrilling with a 2-mm drill-bit is advisable. In the second metacarpal the pins are inserted in a converging manner, at 40–50° to each other, to increase their holding power in the bone. A second pair of pins is then inserted into the distal third of the radius, just proximal to the bellies of the abductor pollicis longus and extensor pollicis brevis muscles. Again, the use of small skin incisions, blunt dissection of the soft tissues, and the protection guide will minimize iatrogenic lesions of the superficial radial nerve branch at this level (Fig. 13.8).

After tightening the fixator clamps, the quality of joint reduction is again assessed under fluoroscopy. If articular congruity is unacceptable (more than 1–2 mm step-off), a percutaneous or formal open reduction, as described previously, is performed with the fixator in place. The choice of surgical approach depends on the localization of the fragment needing additional reduction. Most commonly, the approach between the third and fourth extensor compartments is used. The proximal part of the extensor retinaculum is divided up to the level of the radiocarpal joint and the extensor pollicis longus tendon is freed at the level of Lister's tubercule. The wrist joint capsule is opened transversely and the fragments are manually elevated and reduced against the scaphoid and lunate.

The remaining bone defect after reduction of the fragment could be grafted with autologous iliac bone graft. Bone grafting not only provides additional mechanical support for the articular fragments, but also accelerates bone healing. Even in cases where adequate joint congruity has been obtained with ligamentotaxis alone, primary bone grafting is strongly recommended if massive metaphyseal defects persist after the application of the wrist fixator, since grafting enhances fracture healing and permits early removal of the fixator, allowing early wrist rehabilitation. The use of transverse Kirschner wire fixation from the radial styloid towards the distal radio-ulnar joint depends on the size of the fragments.

Another possibility is the change from an external fixator to angular stable plate after 10–14 days. Cancellous bone grafting is often not necessary.

13.7.4 Volar Plating

Plate fixation results in less radial shortening than external fixation, as well as less pain and improved functional outcomes and grip strength.

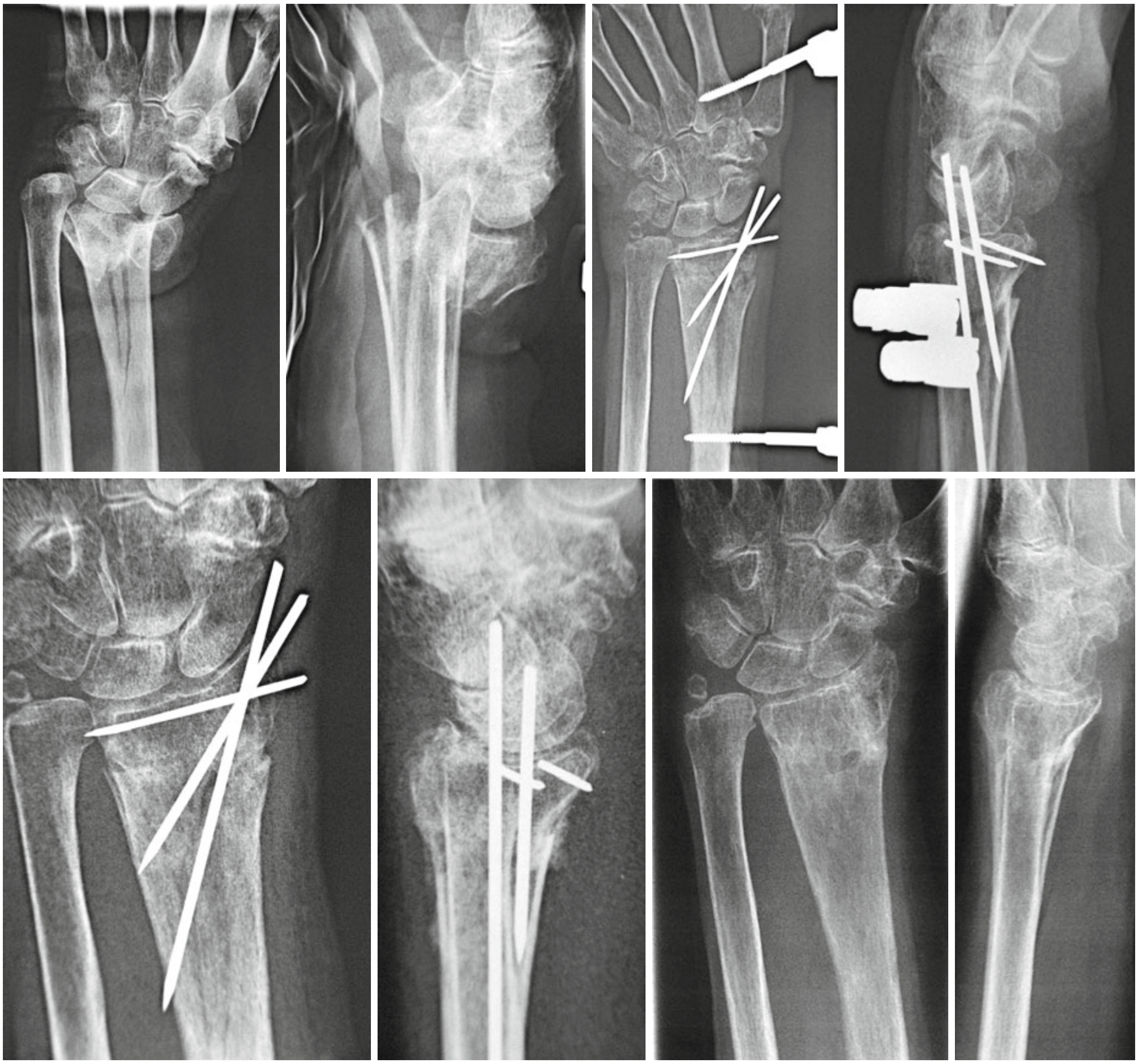

Fig. 13.8 C3 fracture in an 85-year-old woman. External fixator and K-wire fixation. After implant removal undisturbed function

13.7.4.1 Patient Preparation and Positioning

Position the patient supine on the table, with the extremity extended and supported on a hand table. A nonsterile pneumatic tourniquet is placed on the proximal arm.

13.7.4.2 Surgical Approach

Henry's modified palmar approach to the distal radius is used. A straight incision is made between the radial artery and the tendon of the flexor carpi radialis muscle.

Dissection is performed between the radial artery and the flexor carpi radialis tendon. The forearm fascia is divided and the pronator quadratus muscle is detached from the radial bony insertion. The fracture is visualized [18, 20, 21].

13.7.4.3 Reduction

The fracture is reduced manually. Because the palmar cortex is of sufficiently good quality even in very osteoporotic bone, radial length and axial alignment can be restored anatomically. Manual reduction is usually sufficient to restore palmar tilt. To correct the residual dorsal displacement and restore palmar tilt, the distal fragment can be reduced indirectly. The locking plate is fitted/equipped with the threaded drill sleeve and placed in position, where the drill sleeve and the radiocarpal joint line cover a dorsally open

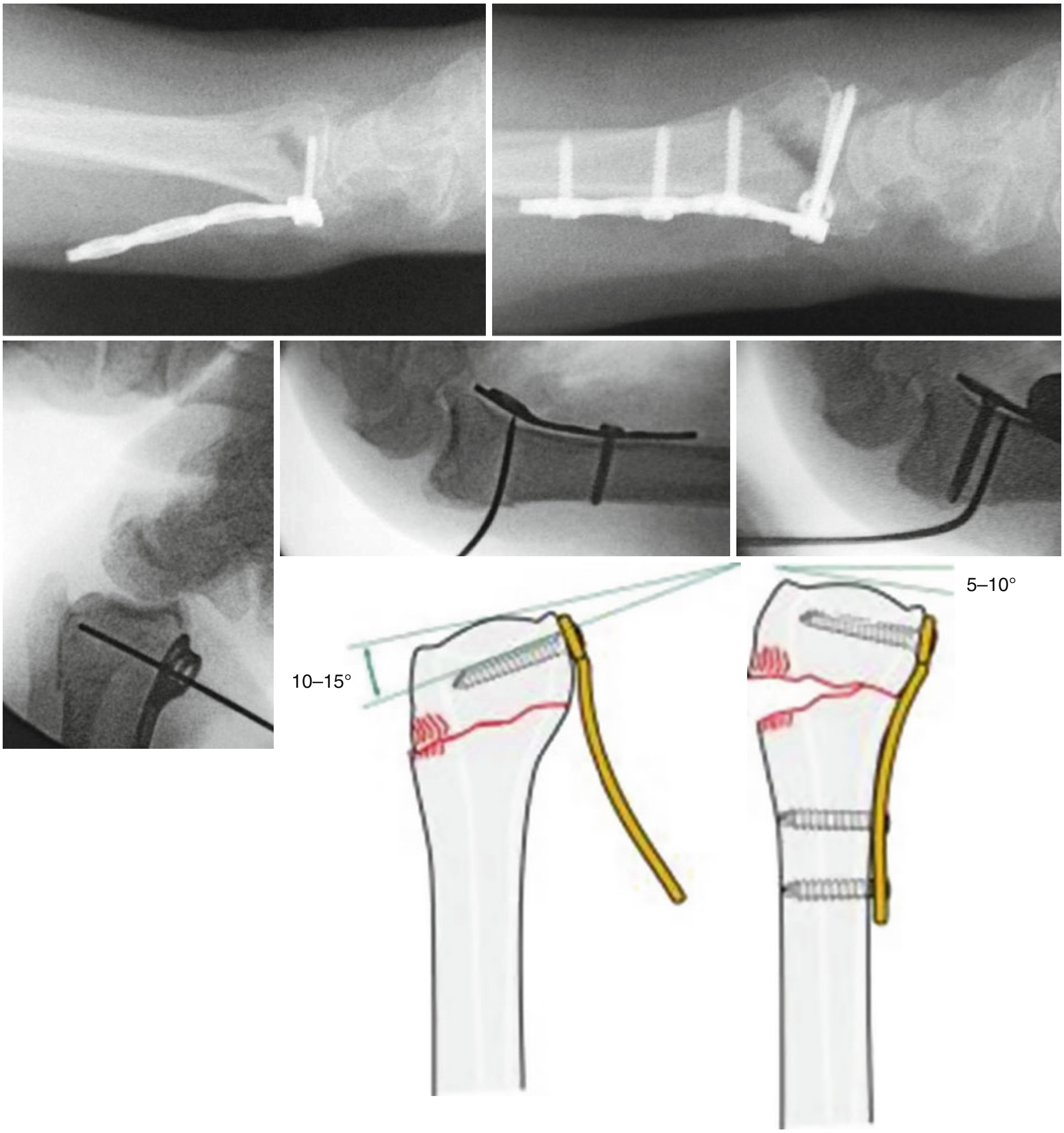

Fig. 13.9 Reduction technique with a plate. The distal screw hole is drilled according to the desired angulation of the distal radius articular surface. Alternatively, K-wires can be used from dorsal into the fracture line or from palmar into the distal fragment

angle of 10°. A K-wire, an LHS, or both are used to fix the plate in this position. The plate is now away from the radial shaft proximally. The shaft of the plate is reduced to the shaft of the radius manually, and the distal fragment is thereby brought into the desired position of slight palmar flexion. The plate acts as an angled blade plate.

As an option, K-wires and Weber clamps can be used to temporarily hold the reduction (Fig. 13.9). The articular surface can be reduced through the fracture

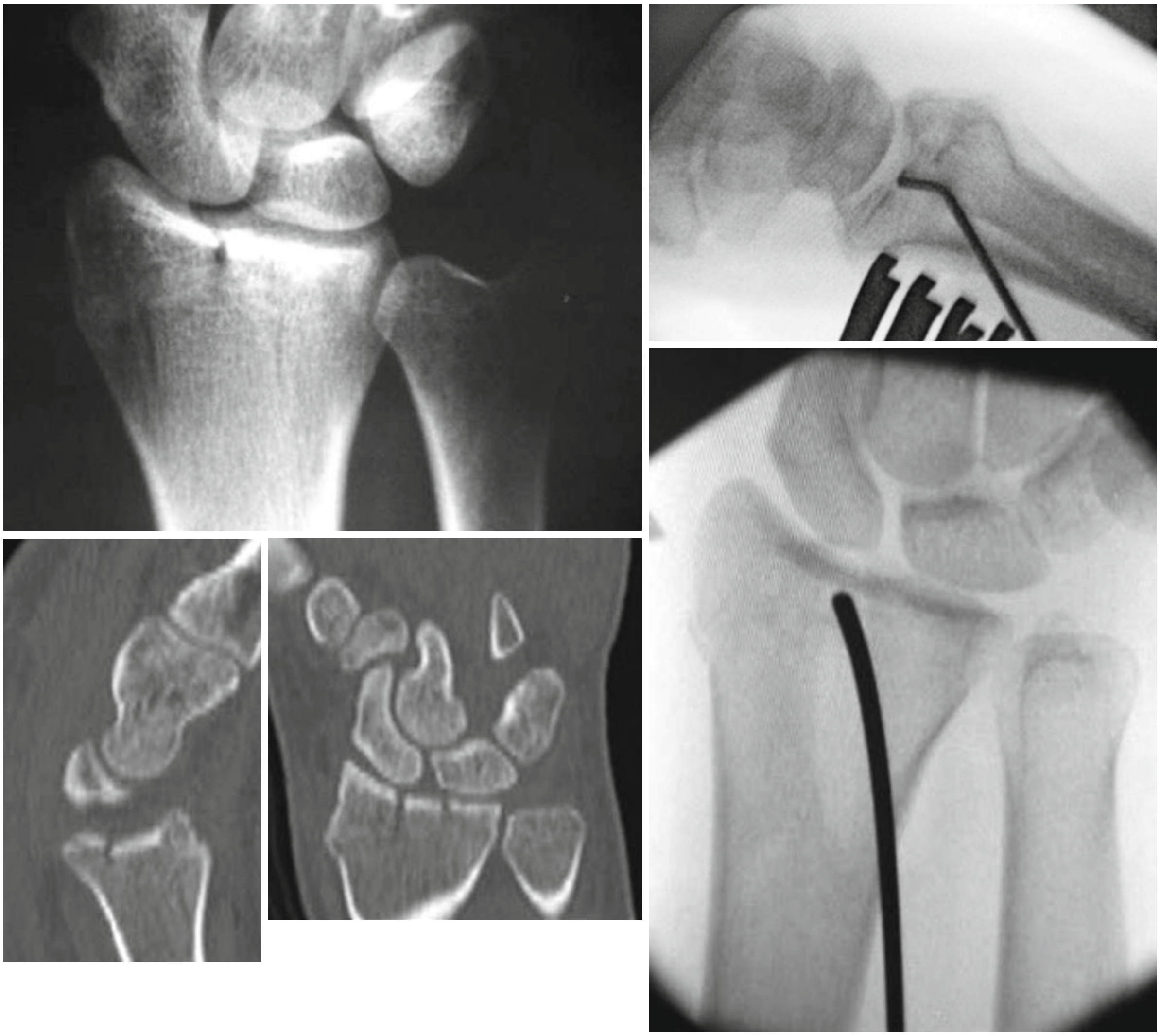

Fig. 13.10 Reduction of the articular surface with the opposite end of a K-wire

gap (Fig. 13.10). Arthroscopy may be helpful for the reduction.

13.7.4.4 Fixation

After manual reduction, the plate is placed in the correct position and fixed with a first cortex screw in the elongated plate hole in the radial shaft. Reduction and plate position are checked by fluoroscopy. As the correct plate position is determined and reduction is completed and secured using a K-wire (optional), the plate is definitively fixed with a second cortex screw of LHS in the most proximal hole of the plate. Internal fixation is completed by inserting the LHS in the distal part of the plate using the threaded drill guide. Care is to be taken when inserting the screws in order to obtain perfect purchase of the screw head in the threads of the plate. In osteoporotic bone, insertion of three distal locking head screws is recommended. After documentation of the osteosynthesis by X-ray, the wound is closed and drained. A palmar or dorsal plaster can sometimes be applied until the wound is healed (Fig. 13.11).

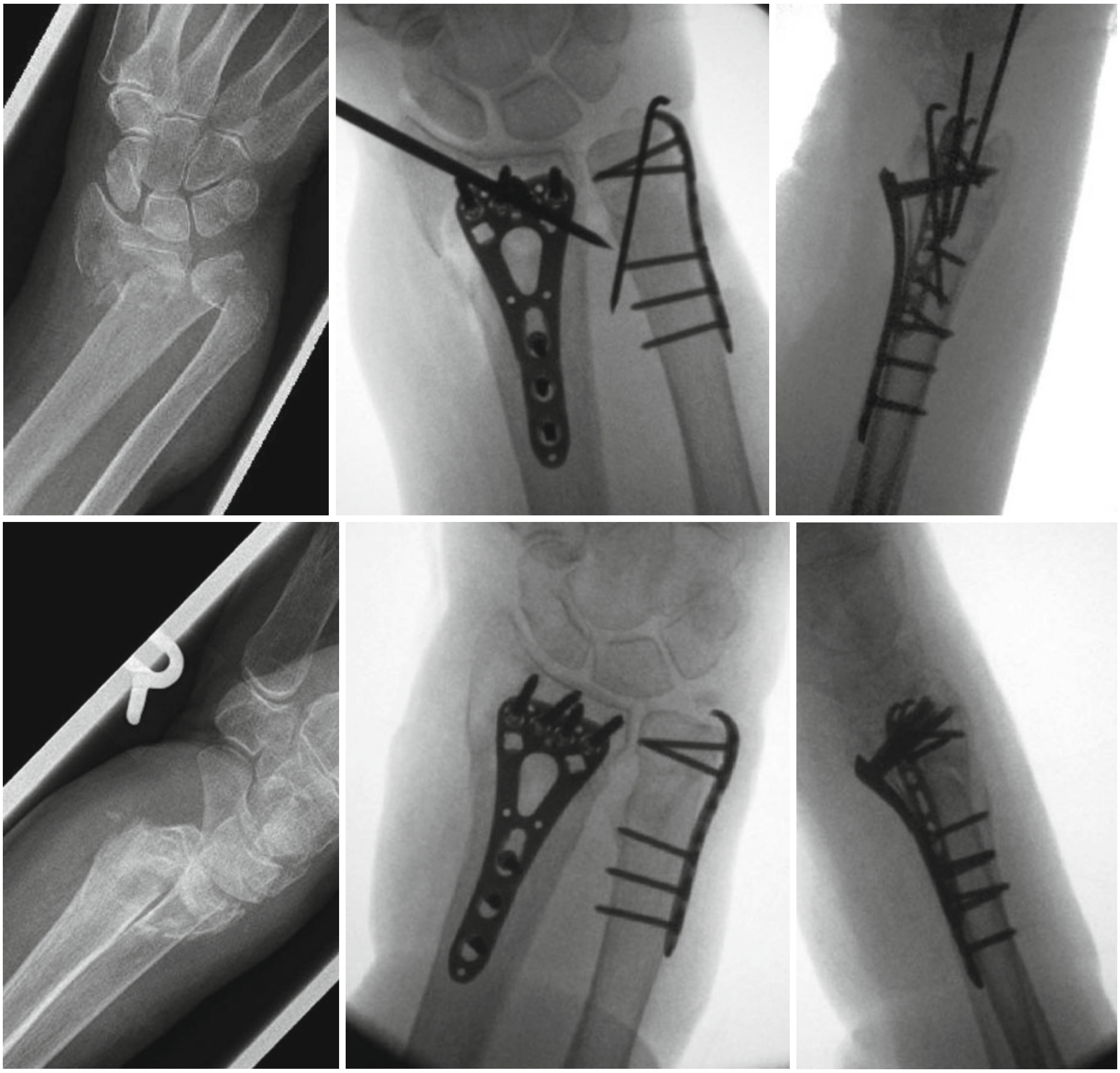

Fig. 13.11 C3 type fracture, reconstruction of the articular surface with 2 K-wires, and plate of fixation of the distal radius and ulna

13.7.4.5 Rehabilitation

Rehabilitation consists of immediate early motion out of the plaster splint under an instruction of a physiotherapist. The hand is used for unloaded daily activities such as eating, personal hygiene, tying a tie, and holding paper. After 6 weeks fracture healing is documented by X-ray and the patient can usually begin loaded activities.

13.7.4.6 Complications

In some cases, the radial "ear" of the T-arm of the plate should be bent back to avoid painful interference with the skin.

Correct positioning of the plate must be checked by fluoroscopy to be sure that the radiocarpal joint is not penetrated by the distal LHS. The LHS must be directed carefully in the correct direction in order to have perfect purchase of the screw heads in the plate hole. The screws must not be overtightened. In very old people with osteoporotic bone and mental alteration, the osteosynthesis should be protected by a closed plaster cast. Correct length of the screws is necessary to avoid interference or rupture of extensor tendons.

Bone grafting is not necessary. The technique is applicable also in osteoporotic bone. A dorsally displaced Colles' fracture with simple, nondisplaced extension of the fracture into the radiocarpal joint can be treated in the same way. These injuries are usually caused by low-energy bending forces and respond to manual ligamentotaxis for reduction.

13.7.5 Dorsal Plating

13.7.5.1 Indication and Approaches

High-energy axial forces lead to impaction of articular fragments into the metaphyseal cancellous bone. According to the three column model, the intermediate column (IC) is divided into two main fragments–dorso-ulnar and palmar-ulnar. The dorso-ulnar fragment is centrally impacted. The radial styloid is separated (radial column RC). These articular fragments do not respond to ligamentotaxis. Formal open revision is indicated to reconstruct the radiocarpal joint surface (IC) under vision. Additionally, this type of injury can be combined with a relevant ligamentous injury to the proximal carpal row. These ligaments can be revised during the dorsal approach by arthrotomy [29].

13.7.5.2 Patient Preparation and Positioning

Supine forearm on hand table, nonsterile pneumatic tourniquet, and prophylactic antibiotics are sometimes required. A straight dorsal incision is performed, centered over the distal radius. The subcutaneous tissue is divided. To access the intermediate column, the extensor retinaculum is incised along the course of the extensor pollicis longus (EPL) tendon. The Z-shape incision spares the distal portion of the tendon sheath to preserve the deflected course of the tendon and allows a flap drawn to the underneath of the EPL tendon during closure in order to protect this tendon from the plate. The EPL tendon is freed and retracted with an elastic thread. Preparation of the intermediate column is now strictly subperiosteal. The second compartment is not touched.

Access to the radial column by preparing between the skin flap and retinaculum towards the radial side, taking care of the superficial radial nerve, which is always visible in the skin flap. The first compartment is incised and the abductor pollicis longus and extensor pollicis brevis tendons are freed enough for an S-plate to be slipped underneath in order to buttress the radial column. Note that the second compartment is left untouched.

As a general rule, the approaches should be extensile, offering sufficient exposure to accomplish the surgical goals and heal with limited scarring. The approaches to the dorsum of the end of the radius and wrist are exposed between the extensor compartments (Fig. 13.12).

13.7.5.3 Reduction

A transverse arthrotomy exposes the radiocarpal joint surface at the level of the lunate facette and partially exposes the scaphoid facette. The proximal carpal row can be revised for any ligamentous injury. The radiocarpal joint is now reconstructed under direct vision by levering the articular fragments towards the carpal row. Any step-off or gap should be eliminated. The dorsal cortical shells help to define length and serve as a buttress after reduction. Single fragments can optionally be fixed temporarily with small K-wires. Distraction of the wrist using an external fixator is helpful during reconstruction of the joint surface. Reduction is checked by image intensification.

13.7.5.4 Fixation

After reduction and preliminary fixation of the intermediate column, a LCP L-plate or T-plate is chosen according to the anatomical configuration and need for fixation of fragments. The plate is precontoured and usually it must be bent back at the distal end and twisted into itself. The plate is fixed with a first cortex screw in the elongated plate hole in the radial shaft. Next, the radial column is buttressed with a precontoured S-plate slipped underneath the tendons of the first compartment. The plate is fixed with a first cortex screw in the elongated plate hole in the radial shaft. Reduction and plate positioning is checked by fluoroscopy.

After correct reduction and plate positioning has been documented by fluoroscopy, the position of the plate is secured by applying a second cortex or locking head screw in the most proximal hole in the shaft. Only then is placement of the distal locking head screws started. The distal locking head screws in the transverse part of the T- or L-plate support the radiocarpal joint surface. An additional bone graft to fill the metaphyseal defect is not required.

The wound is closed in layers. The EPL tendon is partially transposed subcutaneously by creating a retinaculum flap that covers the plate. Suction drainage is used. Only now is the external fixator, if applicable, withdrawn. A removable plaster splint is applied until the wound is clean and the pain has subsided.

13.7.5.5 Rehabilitation

Early motion with assistance of a physiotherapist is started immediately. The plaster splint is changed to a

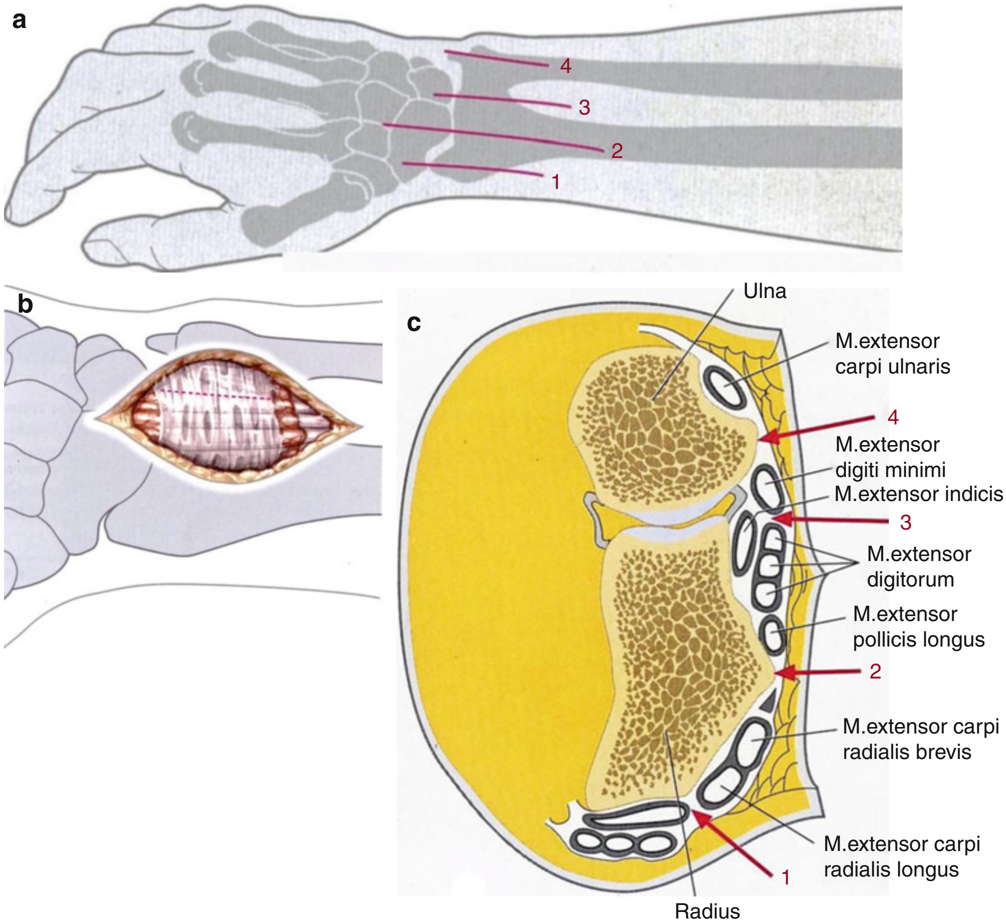

Fig. 13.12 The most common dorsal extensile approaches. Approach 1 for reduction and fixation of radial styloid fractures develops the interval between the first and second extensor compartments. Approach 2 lies between the third and the fourth extensor compartments and is chosen for complex articular fractures. Approach 3 lies between the fourth and the fifth extensor compartments and is preferred when limited open reduction of fractures affecting the lunate facet is required. Approach 4 lies between the fifth and sixth dorsal extensor compartments and is useful for the open reduction of distal ulna and/or repair of the triangular complex (**a, c**). After skin incision, the extensor retinaculum is split. Between extensor digitorum and mextensor digiti minimi on the ulnar side, the distal radius is reached (**b**)

removable Velcro splint. The hand is used for unloaded daily activities such as eating, personal hygiene, tying a tie, and holding paper. After 4–5 weeks, fracture healing is documented by X-ray and the patient can usually start loaded activities.

13.7.5.6 Complications

Rotational deformities can be difficult to handle from a dorsal approach. Hyperextended palmar articular fragments are difficult to control from a isolated dorsal approach. They usually need a palmar plate. Centrally depressed fragments do not response to ligamentotaxis.

The concepts allow for early functional rehabilitation and help to avoid dystrophy. Bone graft is not necessary because of locking implants. Injuries are usually caused by low-energy bending forces and respond to manual ligamentotaxis for reduction.

13.8 Distal Radioulnar Joint Instability

Distal radioulnar joint (DRUJ) instability is commonly associated with a radius fracture.

The primary stabilizer of the DRUJ is the triangular fibrocartilage complex (TFCC). Additional stabilizers such as the ulnocarpal ligaments, extensor carpi ulnaris subsheath, and interosseous membrane have a secondary role. Radial shortening of 5–7 mm can stretch the dorsal and palmar radioulnar ligaments and result in ligament tears. Distal radius fracture angulation also affects the biomechanics of the DRUJ. More than 20°dorsal angulation has also been associated with incongruency of the DRUJ in addition to altered TFCC kinematics, leading to tearing at its peripheral attachments [24]. As the amount of displacement and angulation increases, secondary constraints to joint stability are injured as well, such as the ulnocarpal ligaments, extensor carpi radialis subsheath, and interosseous membrane [24].

13.8.1 Diagnostic

Radiographic findings include ulnar styloid base fracture, widening of the DRUJ interval on PA radiographs, and dislocation of the DRUJ on lateral radiographs. A computed tomography scan can provide additional insight. Axial views of the DRUJ can be compared with the contralateral side. Subluxation or frank dislocation may often be identified, in addition to bony fragments suggestive of palmar or dorsal radioulnar ligament avulsions [24].

After fracture stabilization, DRUJ may be examined under anesthesia and compared with the contralateral side. The most common cause for DRUJ instability is via a fracture through the base of the ulnar styloid and requires the determination of instability after radius fracture internal fixation through manual testing. When managing this fracture, greater than 1 cm of dorsal to palmar translation mandates instability presumption [24].

13.8.2 Treatment

Distal radioulnar joint instability is then addressed through open reduction and internal fixation of the ulna styloid fracture. The styloid ulnar fracture is not addressed if the DRUJ is stable after fixation of the radius and using either fixation of the ulnar styloid or reduction and supination splinting if the DRUJ is unstable [28].

13.9 Complications of Distal Radius Fractures

13.9.1 Malunion

Malunion of distal radial fractures is the most common complication of the injury and is often the underlying cause for other complications such as median neuropathies and distal radioulnar joint problems. The reasons for malunion may be dorsal collapse, loss of radial length, or lunate facet dislocation. Symptomatic malunion is correctable by radial osteotomy with or without ulnar procedures. Restoration of volar tilt will correct carpal alignment [25] and may improve radial length. Osteotomy combined with ulnar procedures is recommended in cases of limited forearm rotation or ulnocarpal impingement [8]. Intraarticular osteotomy may be indicated in patients with intraarticular malunion before arthrosis has developed. Despite the available techniques, however, early intervention with prevention of malunion is a preferable course. Dorsal collapse may be prevented when using a volar-fixed angle plate by inserting at least four screws within the distal fragment. The distal screws of a volar locking plate should be placed within 3 mm of the subchondral bone. Anatomic reduction of the articular fragments can be confirmed by tilted views or arthroscopy or arthrotomy.

13.9.2 Compression Neuropathy

Compression neuropathy of the median, ulnar, or radial nerves is reported as occurring in 8–17 % of distal radial fractures, with the median nerve being most common [1, 5, 14] Median neuropathy may be related to the original injury, particularly in displaced fractures, to immobilization in extreme flexion causing increased carpal tunnel pressures to fracture fragments compressing the nerve [5, 8] or to malunion of the distal radius [1]. Guidelines for the management of median neuropathy associated with distal radial fracture should follow the principles that recommend decompression if a complete lesion persists after reduction of a fracture, if an incomplete lesion deteriorates at any stage or persists unchanged for longer than 7 days, or if the fracture requires operative intervention [8]. In cases with malunion, osteotomy should be considered in conjunction with median decompression. Ulnar and radial neuropathy are less common and are usually treatment related, either from cast compression or fixator pins [5]. Injury of the superficial branch of the radial nerve can be seen in K-wire fixation, external fixator, or volar plate fixation. There exists no safe zone for placement of a percutaneous K-wire. Therefore, a mini-open approach with protection of soft tissues and nerve is recommended.

Injury to the ulnar nerve is rare (2 %). The DCUN (dorsal subcutaneous branch of the ulnar nerve) is noted at a mean of 0.2 cm proximal to the tip of the ulnar styloid. Because of palmar and radial displacement with full pronation at the wrist, this position is recommended for initial skin incision around the distal ulna.

13.9.3 Reflex Sympathetic Dystrophy/ Complex Regional Pain Syndrome

The reported incidence of reflex sympathetic dystrophy varies considerably, from 1.4 to 37 % [2, 3], probably related to different diagnostic criteria. Its underlying cause is obscure, although carpal tunnel syndrome has been implicated in its etiology [8, 12]. Diagnosis is based on several criteria. At least four of the following features should be present: unexplained diffuse pain, diffuse swelling, difference in skin colour and temperature relative to the opposite side, and a limited active range of movement. In addition, these symptoms and signs should be present in an area larger than the area of primary injury and should increase with use.

Treatment should be as early as possible and may be by sympathetic blockade, intravenous guanethidine, corticosteroids, hydroxyl-radical scavengers, vitamin C up to 500 mg/day for 50 days, and intensive physiotherapy. Despite active treatment, the outcome is often poor.

13.9.4 Tendon Rupture

Both flexor and extensor tendon ruptures occur after distal radial fracture, although the former are extremely rare. Extensor pollicis longus rupture is by far the most common, although its incidence is usually less than 1 % [5]. Various mechanisms of injury have been proposed, although the most popular is probably a combination of attrition and impaired blood supply [11].

Most tendon ruptures occur several weeks to months after injury [5] and may be associated with minimally displaced or undisplaced fractures. Direct tendon repair is not usually possible because the abnormality extends over several centimeters. Treatment is most often by extensor indicis proprius transfer, which yields good functional results (Hove 1994). To avoid extensor tendon injuries, dorsal plates should be covered by extensor retinaculum; symptomatic dorsal plates or volar screws should be removed. Drilling should be performed carefully with volar plate fixation. Pronator quadratus closure over a volar plate may decrease irritation to the flexor tendons.

13.9.5 Treatment-Related Complications

Complications related to treatment of distal radial fractures are, unfortunately, common occurrences [6]. Some of the complications discussed above may be treatment related, such as carpal tunnel syndrome induced by a cast. It must be remembered that cast complications are as frequent as operative complications and that the permanent disability caused by poor cast application may prove more serious than that caused by skeletal deformity [5].

Tightness of a cast can lead to swelling of the hand and fingers, which, if not relieved, may lead to intrinsic contractures and finger stiffness. This must be prevented by elevation, splitting, or removing the cast, and early finger movements. A cast must not be applied over the metacarpophalangeal joints, as this will contribute to finger stiffness.

Pin-related problems, usually infection or radial neuritis, may be caused by external fixation or percutaneous pinning. They are rarely serious and are usually preventable with good techniques such as open pin placement and meticulous pin track care. Other surgical complications are discussed in the relevant sections.

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14 Management of Hand Injuries

Susanne Hellmich and P.M. Vogt

14.1 Complex Hand Injuries

14.1.1 Introduction

Complex hand injuries are not well defined in the literature but generally refer to severe injuries of multiple important structures that may endanger the survival or severely impair functions of the hand. The quality of the treatment may determine the further usability of the entire upper limb in daily life and work, and thus the ability to work and quality of life of the affected individual. The management of such a complex hand injury requires:

Thorough anatomical understanding of the hand and carpus

Specific surgical planning

Surgical experience in bone surgery, microsurgery, and soft tissue reconstruction with local, pedicled, distant flap, and microsurgical flaps.

14.1.2 Treatment Principles

Complex hand injuries often result from high-energy trauma, such as car accidents and crush or blast injuries. Management includes ruling out injuries to other organ systems, which may be life-threatening, and adhering to the following priorities:

1. Survival of the patient
2. Maximum tissue preservation of the injured limb
3. Preservation or restoration of function
4. Aesthetic restoration

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14.1.3 Evaluation of Injury

Accurate evaluation begins with a detailed report from the patient or other observers of how the injury occurred. The possibility of any coexisting injuries to other areas must be considered. The mechanism of injury gives clues to the degree of crushing, contamination, and inappropriate first aid. Complex injuries are also frequently combined injuries (e.g., circular saws accidents), which may affect soft tissue (vessels, nerves, muscle-tendon units), bones, and joints and involve different types of injury, including

- Lacerations (with injury of structures) (Fig. 14.1)
- Severe bruising (tissue contusion)

Fig. 14.1 Deep laceration wound of the hand with injury of thenar muscles

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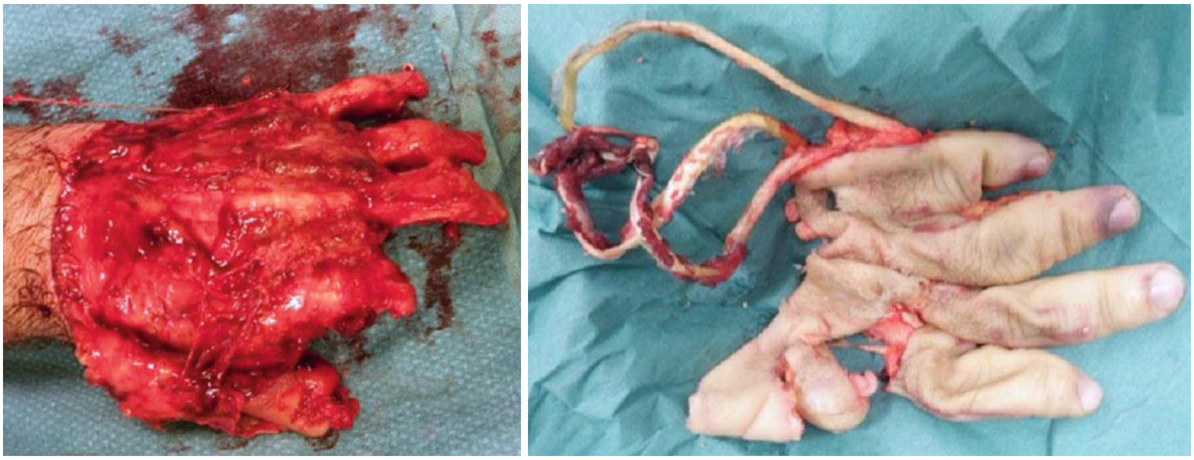

Fig. 14.2 Degloving injury of the hand

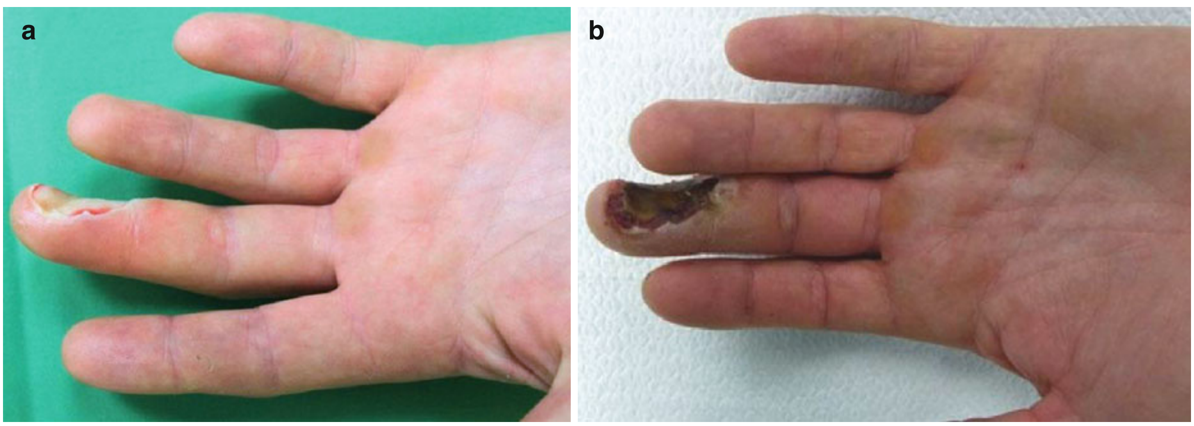

Fig. 14.3 Entrance site of a low-voltage burn (**a**), after 5 days before debridement (**b**)

- Avulsions (with traction injury) (Fig. 14.2)
- Thermal destruction (Fig. 14.3)

There are many classic injuries associated with certain types of accidents. Falling on the outstretched palm with hyperextension of the wrist is often the mechanism for fracturing the scaphoid.

14.1.4 Planning

Treatment planning is based on careful analysis of the initial injury and the resulting defect after surgical primary care, the lost functions, and the necessary reconstruction, including soft tissue coverage.

Surgical treatment is directed at achieving the following goals:

1. Complete removal of infected or avital tissue
2. Restoration of tissue perfusion
3. Bony stabilization with minimal additional soft tissue trauma
4. Stable, well-perfused, and aesthetically adequate soft tissue coverage
5. Early mobilization of the limb in order to minimize post-traumatic scarring and restore function and motion of the hand

Many factors enter into the treatment plan for each individual patient, including age, education, vocation, hand dominance, expectations, and even hobbies.

14.1.5 Surgical Procedure

The surgical procedure may be divided into several steps:

14.1.5.1 Acute Care/Emergency Room Management

- Review of the injury and possible additional injuries (ABC rule, exclusion of danger to life and involvement of sensory organs, especially eyes and ears)

Fig. 14.4 Radiograph of amputate and hand

- Hemostasis of acute bleeding (by tourniquet, usually no clamping of vessels)
- Reduction of bony deformities
- Control of tetanus protection, if necessary booster or vaccination, antibiotic administration
- Cooling of devascularized tissue (leaving intact skin bridges)

Polytraumatized patients, that is, patients with life-threatening injury to one or more organ systems, must always be judged in terms of the leading injury ("life before limb"). Treatment of hand injuries is limited to temporary stabilization of bone injuries and bleeding. For clinically unstable patients, amputations may be more useful than lengthy reconstructions.

After determining the leading injury, triage is performed and hemostasis and prevention of life-threatening blood loss is the first goal in the emergency room. Removal of a compression bandage often significantly improves the perfusion situation and enables further evaluation, including pulse status and sensibility testing.

The exact medical history includes factors such as age, occupation, recreational interests, additional illnesses, medications, allergies, and other factors, such as nicotine consumption. It is always important to document the exact circumstances of the accident and mechanism, as this can significantly influence further treatment and prognosis. Radiographs of the affected limb in two planes (also amputate) should be performed (Fig. 14.4).

14.1.5.2 Anesthesia and Use of Tourniquet

Anesthetic requirements for hand surgery are few and simple. The patient should be free of all pain and lie quietly throughout the operation, including application of the dressing. The vast majority of patients are healthy young people for whom a wide variety of general or regional nerve block techniques are equally satisfactory.

In case of complex hand injuries or multiple amputations of finger with expected long operation times, the operation should be performed under general anesthesia, if necessary, with brachial plexus. Postoperative monitoring in the ICU should be considered.

Regular use of a pneumatic tourniquet to maintain a bloodless operation has been a major contribution to reparative hand surgery and is essential both for

Fig. 14.5 Preoperative view of severe self-wrist cutting injury (**a**); View after debridement: complete transection of tendon, nerve, and vessel with defect (**b**)

the identification of injured structures and to protect uninjured ones.

In most cases, one and a half hours ischemia time is sufficient for identification of injured parts, debridement, and dissection. Most of the repairs can be performed following the release of the tourniquet if necessary.

The pressure of the pneumatic tourniquet should not be above 300 mmHg on the adult upper extremity and proportionally less for children.

14.1.5.3 Surgical Debridement

Debridement of complex hand injuries follows several important rules

- Wound excision and aggressive debridement of necrotic and ischemic tissue, especially muscle
- Preservation of critical structures (nerves, tendons, and arteries)
- Marking of important structures such as nerves, blood vessels and tendons for any secondary reconstructions (Fig. 14.5).

In amputation injuries, during initial debridement, well-preserved or vascularized tissue components (spare parts, such as bones, tendons, nerves, or blood vessels) should be preserved for use in reconstruction or soft tissue coverage (fillet flap, skin grafts).

The extent of debridement in "crush injuries" is often difficult to assess. Wound assessment can be complicated, especially with closed injuries, because a significant soft tissue injury case is sometimes detected preoperatively but underestimated in many cases.

14.2 Bone and Joint Reconstruction

Fractures of the hand are the most common of all fractures. Radiographs are required in at least two planes to confirm clinical impressions and to demonstrate the extent of injury. CT scan may be necessary with fracture of the hook of the hamate or of the scaphoid.

Stabilization of bone injuries is usually performed by simple, fast, and less traumatic methods, for example, K-wires or external fixation; it is less often performed with plating.

Important strategies in the care of bony injuries are:

- Fracture visualization by minimal wound enlarging, without destruction of periosteum

Fig. 14.6 Open fracture with segmental bone loss and severe soft tissue trauma (**a**). The mini Hoffmann external fixation device applied for a complex proximal phalanx fracture; due to external fixation, a primary tendon repair can be achieved (**b**)

- Maximum length preservation; bone reduction only if for the primary soft tissue closure or for bone and nerve reconstruction necessary
- Accurate anatomical fracture reduction with special consideration of joint surfaces
- Bridging of defects with external fixation or plate (Fig. 14.6)
- Complex bony reconstruction, for example, iliac crest bone graft is usually performed secondarily

Bony stabilization is recommended to enable early movement therapy. Examples include

- Radius/ulna – plating (Fig. 14.7)
- Wrist – compression screw/K-wires, reconstruction of injured ligamentous structures, stabilization with K-wires
- Metacarpals – mini plate fixation for early mobilization (Fig. 14.8)

To exclude additional injuries of the wrist or fingers, they are moved under the imager to detect, for example, overlooked ligament injuries or dislocations.

In a perilunate dislocation, open reduction and suture of carpal ligaments (especially the SL ligament) should be performed (Fig. 14.9). In joint destruction a primary fusion (arthrodesis) in appropriate function may be advisable.

14.3 Digital Joint Injuries

Dislocations of the metacarpophalangeal (MP) finger joints are rare. They usually result from falling on the outstretched hand or another mechanism that forces the MP joint into severe hyperextension. They are limited to the index and the small fingers.

These are classified as simple when reduction is easily accomplished and complex when soft tissue elements preclude closed manipulative reduction. After reduction, protection against recurrent injury is provided initially by splinting and then by taping the involved finger to a normal adjacent digit for 2 or 3 weeks. If closed reduction is unsuccessful, then the injury becomes a complex type of dislocation that requires an open reduction.

Fig. 14.7 Fractured radius and ulna treated with plating of both bones

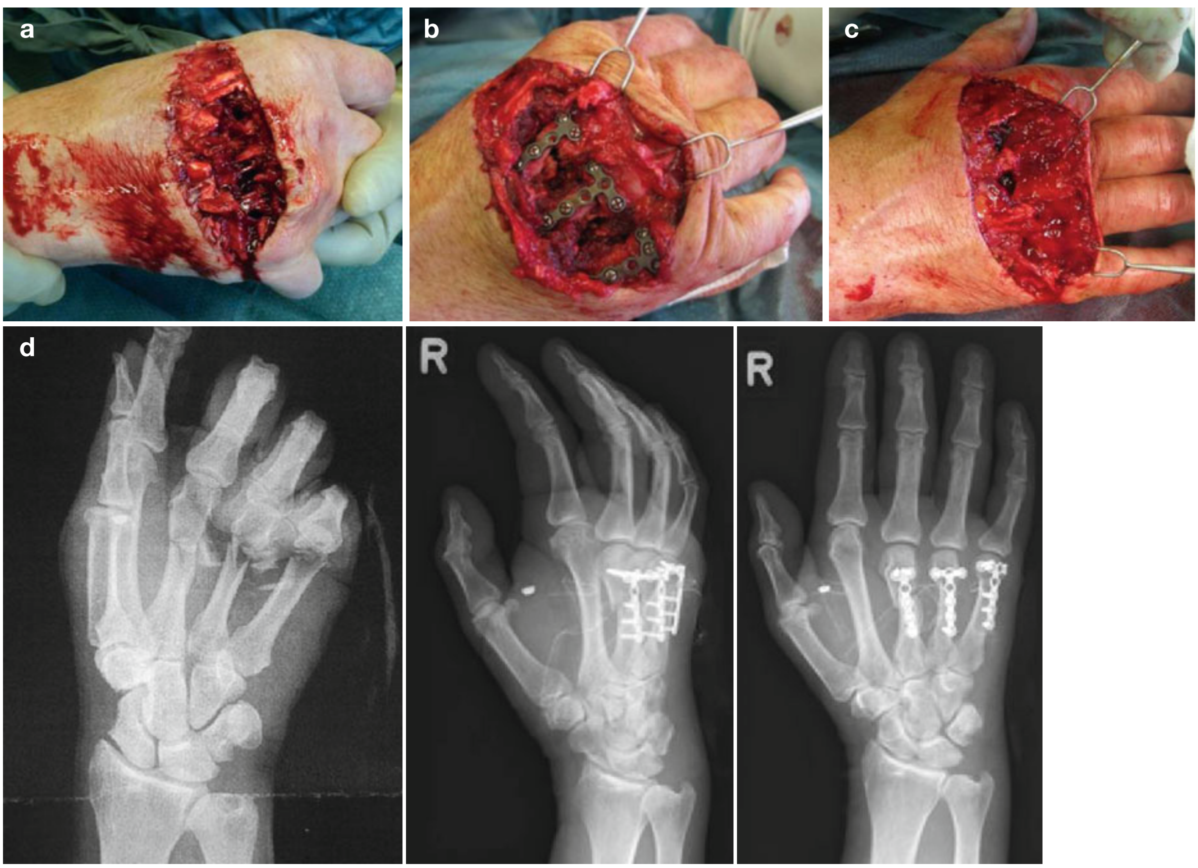

Fig. 14.8 Circular saw injury of the hand with open metacarpal fractures, segmental bone loss, extensor tendon injury and dorsal soft tissue injury (**a**); metacarpal shaft fractures 3–5, mini plate fixation with some shortening of the metacarpal (**b**); repair of extensor tendon (**c**); radiograph preoperatively and after open reduction and internal fixation with 2.3 mm dorsal plate (**d**)

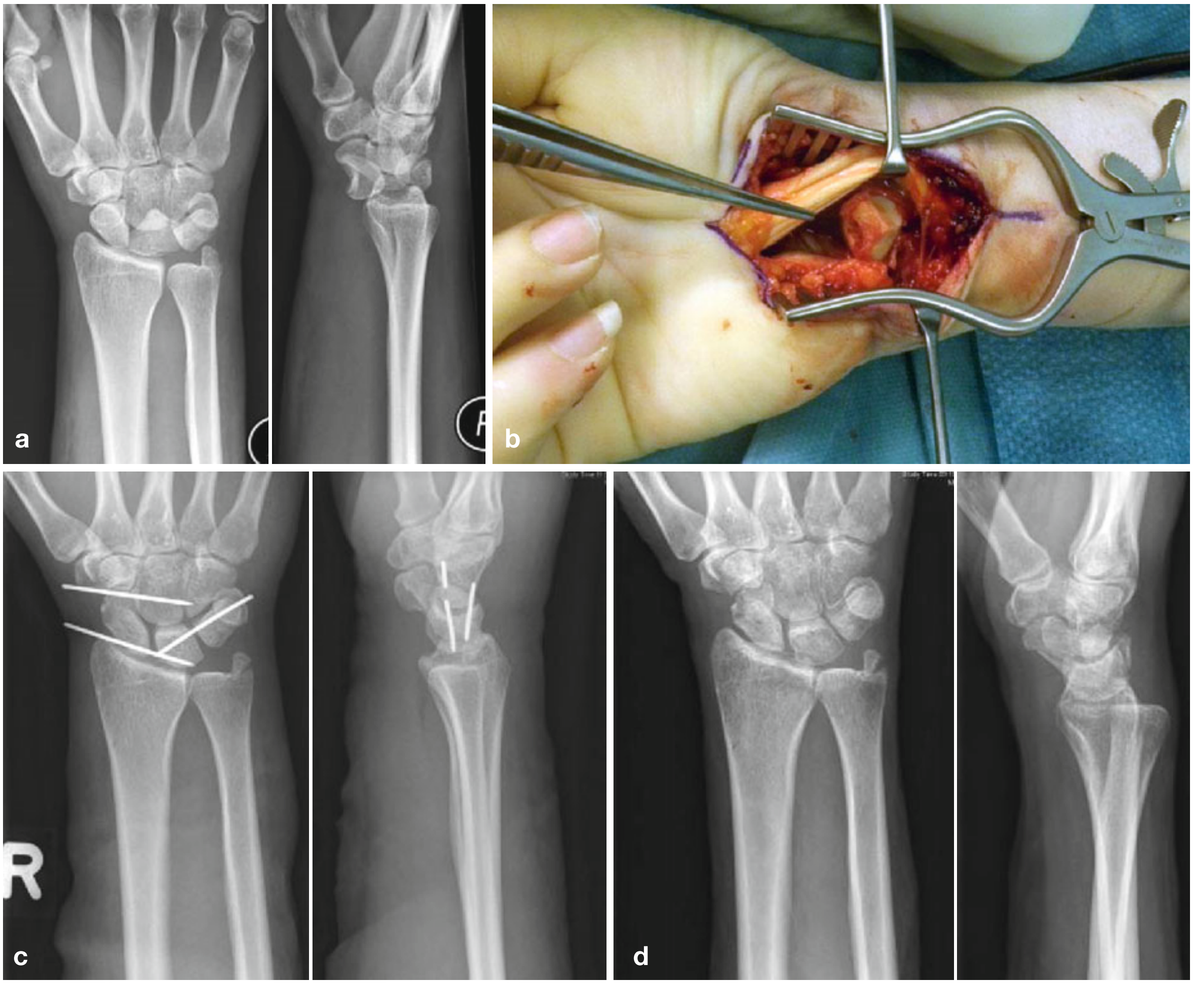

Fig. 14.9 Preoperative radiograph showing dorsal perilunate dislocation in which the lunate dislocates from its fossa and is rotated more than 90° (**a**); intraoperative image showing the dislocated lunate (**b**); after open reduction and K-wire fixation (**c**); after 12 weeks and K-wire removal (**d**)

Stability and pain-free motion of proximal interphalangeal (PIP) joints is extremely important to hand function. Therefore, injury to these joints warrants high priority in treatment. PIP joint dislocations are usually dorsal and result from force on the end of digit with hyperextension (Fig. 14.10).

PIP joint injuries that are stable with active motion can be treated by immobilization with a dorsal splint, usually in 20–30° of flexion for comfort and to rest the soft tissues. The period of immobilization ranges from as little as 3–5 days for mild hyperextension injuries to 7–14 days for dislocations and stable fracture dislocations. Duration of immobilization is individualized, depending on the extent of the injury and resultant amount of soft tissue swelling.

14.4 Tendon Suture and Reconstruction

The prognosis for tendon repairs is determined primarily by what tissues lay in contact with the repair of the tendon.

Extensor tendon injuries of the hand represent common injuries that are underestimated in many cases. If there is a delay in diagnosis and the primary injury is overlooked, deformities (e.g., buttonhole or boutonniere deformity, swan neck deformity) may have already been made. Secondary reconstruction after extensor tendon injuries is more difficult and yields worse results than primary care.

14.4.1 Zones of Extensor Tendon Injury

The dorsum of the hand, wrist, and forearm are divided into eight anatomic zones to facilitate classification and treatment of extensor tendon injuries. The most widely used classification system is that described by Verdan.

Zones 1, 3, 5, and 7 lie over the distal interphalangeal joint (DIPJ), proximal interphalangeal joint (PIPJ), metacarpophalangeal joint (MCPJ), and wrist joint, respectively.

The even numbers are allocated to the intervening zones. The zones of the thumb differ from the finger as there are only two phalanges. They are numbered 1–5, with zones 1, 3 and 5 overlying the interphalangeal joint (IPJ), MCPJ, and wrist joint, respectively. The even numbers, 2 and 4, apply to the intervening zones.

Fig. 14.10 Open PIP joint dislocation of the middle finger, palmar plate rupture of the ring- and small finger (**a**); preoperative radiograph (**b**); radiograph after treatment with protected motion (Extension Block Splint) (**c**); 12 month follow-up, the patient had no pain and achieved functional range of motion (**d**)

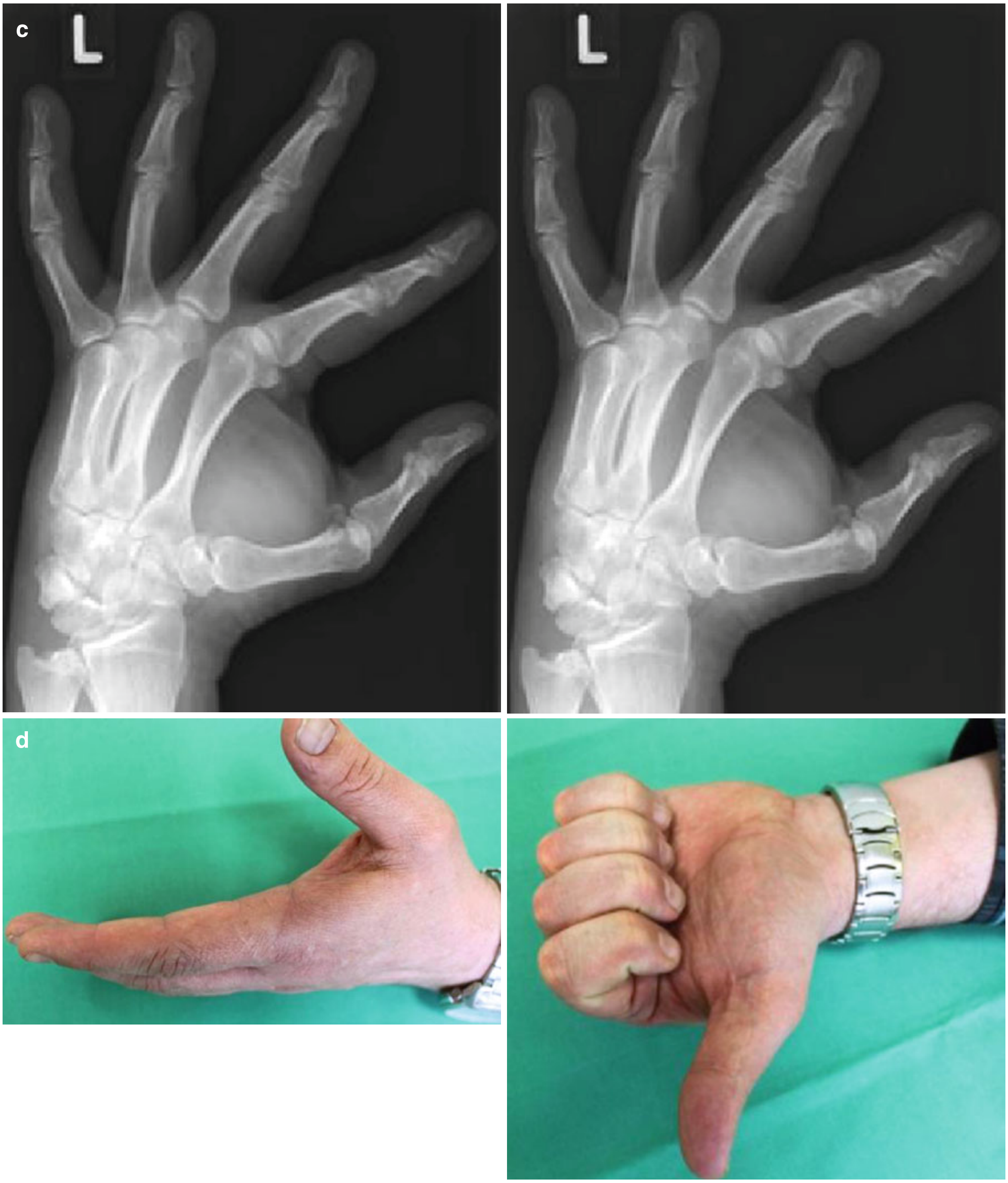

Fig. 14.10 (continued)

- Zone 1 (distal interphalangeal [DIP] joint)
- Zone 2 (middle phalanx)
- Zone 3 (proximal interphalangeal [PIP] joint)
- Zone 4 (proximal phalanx)
- Zone 5 (metacarpophalangeal [MCP] joint)
- Zone 6 (dorsum of hand)
- Zone 7 (wrist)
- Zone 8 (dorsal forearm)

Extensor tendon injuries may require operative intervention, depending on the complexity of the injury and the zone of the hand involved.

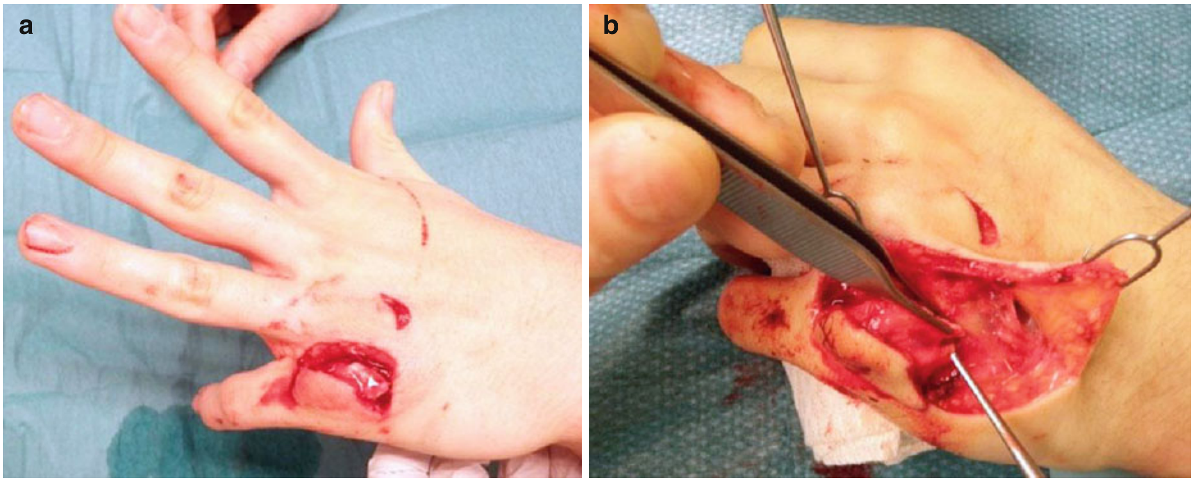

Fig. 14.11 No active extension of the small finger due to extensor tendon injury (**a**); intraoperative image showing tendon injury in zone 6 (**b**)

Zone 1 injuries, otherwise known as mallet injuries, are often closed and treated with immobilization and conservative management where possible. Zone 2 injuries are conservatively managed with splinting. Closed Zone 3, or "boutonniere," injuries are managed conservatively unless there is evidence of displaced avulsion fractures at the base of the middle phalanx, axial and lateral instability of the PIPJ associated with loss of active or passive extension of the joint, or failed nonoperative treatment. Open zone 3 injuries are often treated surgically unless splinting enables the tendons to come together. Zone 5 injuries are often caused by human bites and, require primary tendon repair after irrigation. Zone 6 injuries are close to the thin paratendon and thin subcutaneous tissue and require strong core-type sutures and then splinting; they should be placed in extension for 4–6 weeks. Complete lacerations to zone 4 and 6 involve surgical primary repair followed by 6 weeks of splinting in extension (Fig. 14.11).

Zone 8 requires multiple figure-of-eight sutures to repair the muscle bellies and static immobilization of the wrist in 45° of extension.

14.4.2 Zones of Flexor Tendon Injury

The five flexor tendon zones are modifications of Verdan's original work, which based zone boundaries from distal to proximal on anatomic factors that influenced prognosis following flexor tendon repair. The five zones discussed below apply only to the index through small fingers; separate zone boundaries exist for the thumb flexor tendon.

- Zone 1 extends from just distal to the insertion of the superficialis tendon to the site of insertion of the flexor digitorum profundus tendon (FDP).
- Zone 2 is often referred to as "Bunnell's no man's land," indicating the frequent occurrence of restrictive adhesion bands around lacerations in this area. Proximal to zone 2, the flexor digitorum superficialis (FDS) tendons lie superficial to the FDP tendons. Within zone 2 and at the level of the proximal third of the proximal phalanx, the FDS tendons split into two slips, collectively known as Camper chiasma. These slips then divide around the FDP tendon and reunite on the dorsal aspect of the FDP, inserting into the distal end of the middle phalanx.
- Zone 3 comprises the area of the lumbrical muscles origin between the distal margin of the transverse carpal ligament and the beginning of the critical area of pulleys or first annulus. The distal palmar crease superficially marks the termination of zone III and the beginning of zone II.
- Zone 4 is the zone covered by the transverse carpal ligament, including the carpal tunnel and its contents (the nine digital flexors and the median nerve).
- Zone 5 extends from the origin of the flexor tendons at their respective muscle bellies to the proximal edge of the carpal tunnel.

14.4.3 Tendon Healing

The following factors predict tendon healing: age, overall health condition, scar formation disposition, motivation, injury risk based on Verdan's zones, injury type, synovial containment, and surgical technique. Three phases of tendon healing are defined. First, a migration of peripheral cells and invasion of blood vessels occurs and, second, the tendon and surrounding tissues heal. Remodeling happens in the third phase of healing as a result of movement and function of the tendon. This is the ratio of the widely recommended early passive movement therapy, which leads to better supply and strength of the tendon.

The tendon gains its daily life loading capacity after 12 weeks of healing, and sporting activities are allowed no sooner than 4 months after injury. The remodeling process can last up to 12 months.

Regarding restoration of tendon function, the following guidelines apply:

- Excision of bruised hand intrinsic muscles (especially Mm. interossei and lumbricales) to prevent ischemia and subsequent contracture
- Reconstruction and seam of the A2 and A4-ring belts to prevent bowstring phenomenon
- If necessary, primary tenodesis or tendon transposition surgery
- Late reconstruction using tenolysis, tendon transposition, transplantation, or functional muscle transplantation

Tendon sutures, if possible; the superficial digital flexor tendon can be used as a donor in a primary operation. In a secondary reconstruction, long segment splintering, usually with silastic rod insert and subsequent tendon transplant, is performed (e.g., the PL tendon). The injured structures must be identified during the initial stage and marked.

14.5 Treatment of Vascular Injuries

Important considerations in the reconstruction of vascular lesions, which generally take place only after the treatment of bone and tendon injuries, are:

- Creation of temporary shunts in critical ischemia
- Preparation of vessels with microsurgical instruments under direct vision with a tourniquet
- Use of a Fogarty catheter with proximal and distal vascular injuries
- Return reduction of vessels until healthy, uninjured tissue is reached (Caution: intima damage in avulsion injuries)
- Regular flushing of the vessels with heparin solution (10 U/ml)
- Vascular sutures under the microscope, outside the zone of injury
- Length gain by ligation or removal of side branches, diffraction from adjacent joints of interposition vein grafts (in reverse flow direction)
- Vein grafts are introduced outside the zone of injury and previously dilated (Fig. 14.12)
- Reconstruction of both vascular trunks of the radial artery and the ulnar artery

In avascular limbs, especially macro-replantations, revascularization is the first priority, before tendon and nerve sutures. Bruised or avulsed vessels must be cut behind the zone of contusion. For vein harvesting for long defects, the greater saphenous vein or veins of the forearm are suitable as interposition grafts.

For revascularization proximal to the hand, a fasciotomy is usually required to prevent compartment syndrome as a result of reperfusion. If possible and appropriate, an attempt should always be made at revascularization. If this is not successful, an amputation can still be performed. The main indicative factor is always the expected functional result in the context of age, profession, and the favorite leisure activities of the patient.

In complex amputation injuries, for example, with severance of multiple fingers and the thumb, an extraanatomical reconstruction by heterotopic replantations is an option to achieve basic grip function.

14.6 Nerve Reconstruction

Nerve reconstruction surgery is normally performed as a last step before soft tissue coverage:

- Shortening of the nerves until healthy fascicles become visible
- Epineural nerve suture under a microscope to restore the fascicular structure
- Nerve suture, always without tension (Fig. 14.13).

Nerve stump approximation is possible by flexion of adjacent joints. In replacement of nerves (e.g., ventralization of the ulnar nerve), for smaller defects (<2 cm) artificial nerve conduits can be used; otherwise, nerve grafting (sural nerve, sensory nerve

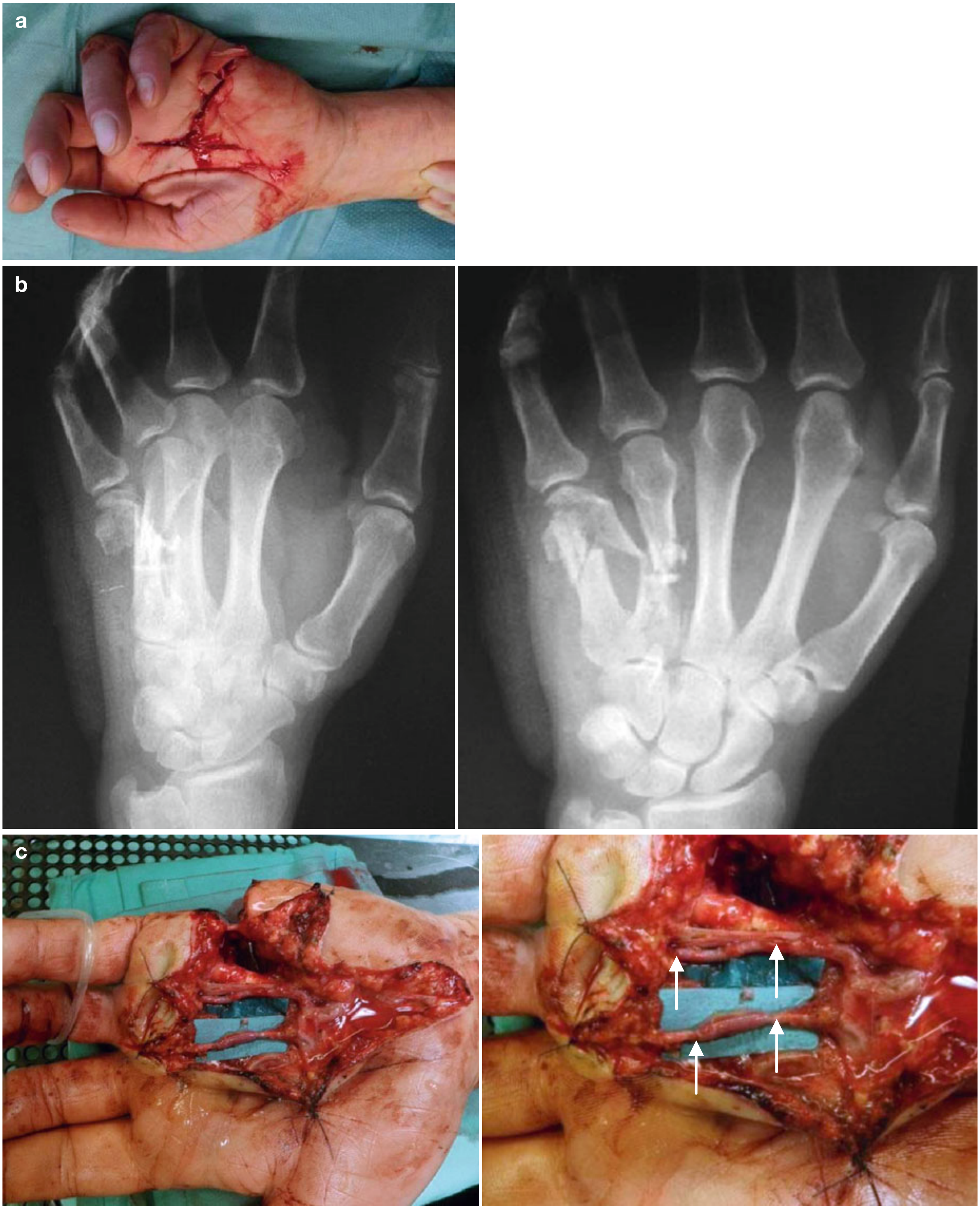

Fig. 14.12 Traumatic partial amputation of ring and small finger (**a**); radiograph showing severe bone crush of metacarpals (**b**); revascularization with vein grafts (*arrow*) (**c**)

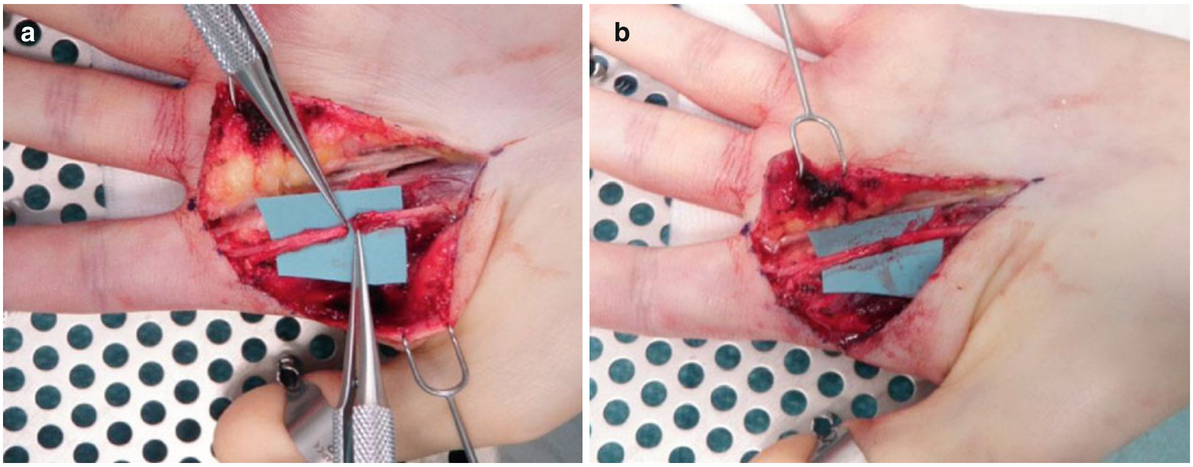

Fig. 14.13 Injury of the proper digital nerve (PDN) (**a**); primary tensionless repair (**b**)

forearm) is necessary. If a primary nerve suture without tension is not possible, nerve stumps are marked and nerve reconstruction is performed secondary to consolidation of wound conditions.

14.7 Soft Tissue Coverage

Final soft tissue coverage should never be enforced. If necessary, a temporary wound closure can be achieved by a synthetic skin substitute (Epigard®) or a vvacuum-assisted closure (V.A.C.®).

- Definitive soft tissue wound closure is performed in a stable situation, possibly after repeated debridement (often after 5–10 days).
- Temporary wound conditioning should be performed, possibly with (V.A.C.®) (contraindicated in infection or bleeding persists).
- Movable joints and tendons should be covered with well-vascularized, thin, and movable tissues (flaps).
- Exposed nerves or vessels must be primarily covered by local flaps, pedicled distant flaps, or microsurgical tissue transplantation
- All "white structures" (tendons, bones, ligaments, joints) should be covered with a flap.
- Violation of the fingertips without exposed bone often heals by secondary intention (OPSITE™ FLEXIGRID™ film dressing) (Fig. 14.14)

Time-proven and reliable pedicled flaps in finger, hand, and wrist wounds are the Moberg flap, cross finger flap, intrinsic flaps (e.g., Foucher or DMCA flap), groin flap, distally pedicled posterior interosseous artery flap (Fig. 14.15), and the radial forearm flap.

In the groin flap, the sensory lateral femoral cutaneous nerve can be included and connected using microsurgery. Usually the pedicle is separated off after about 2 weeks; the final flap inset is performed after 3 weeks. Disadvantages include limited mobility of the patient with increased thrombotic risk, which makes prophylaxis necessary to prevent potentially life-threatening complications, such as pulmonary embolism. Thinning operations of the flap are usually necessary, in addition to long-term physiotherapy to prevent stiffness (Fig. 14.16).

Defects in the region of the distal forearm are commonly covered using the gracilis, latissimus, lateral arm, or anterior lateral thigh (ALT) flaps (Fig. 14.17).

Note that, when planning microsurgical flaps after avulsion injuries, occult vascular injuries with intima damages may complicate early tissue transplantations.

14.8 Amputation Injuries of the Hand

The establishment of microsurgery has enabled the restoration of the hand after traumatic amputation injuries, even in severe injuries; valuable basic function can often be reconstructed. Survival rates of replanted extremity parts have reached more than 80%. However, today, criteria for success includes not only survival

Fig. 14.14 Horizontal amputation of the distal soft tissue of the index finger with exposure of the distal tuft (**a**); 6 weeks after secondary healing with dressing changes (**b**)

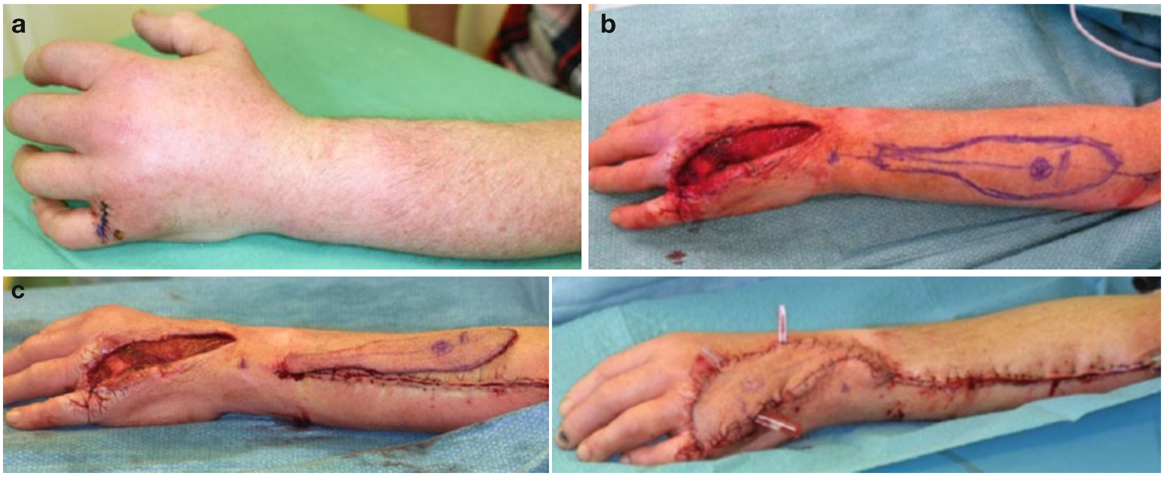

Fig. 14.15 Massive hand infection due to a primary overlooked joint injury (**a**); defect with exposed tendon after debridement (**b**); Coverage of the defect with a distally pedicled, fasciocutaneous posterior interosseous artery flap (**c**)

but the functional value of the reconstructed hand, including their sensibility. Results even with modest functional recovery can justify such operations. This chapter presents indications, preoperative management, surgical technique, and postoperative treatment of amputation of the hand.

14.8.1 Definition

Amputation is defined as complete detachment of a body part, whereas subtotal amputation is an interruption of blood supply, which, by definition, without immediate restoration would lead to necrosis of the

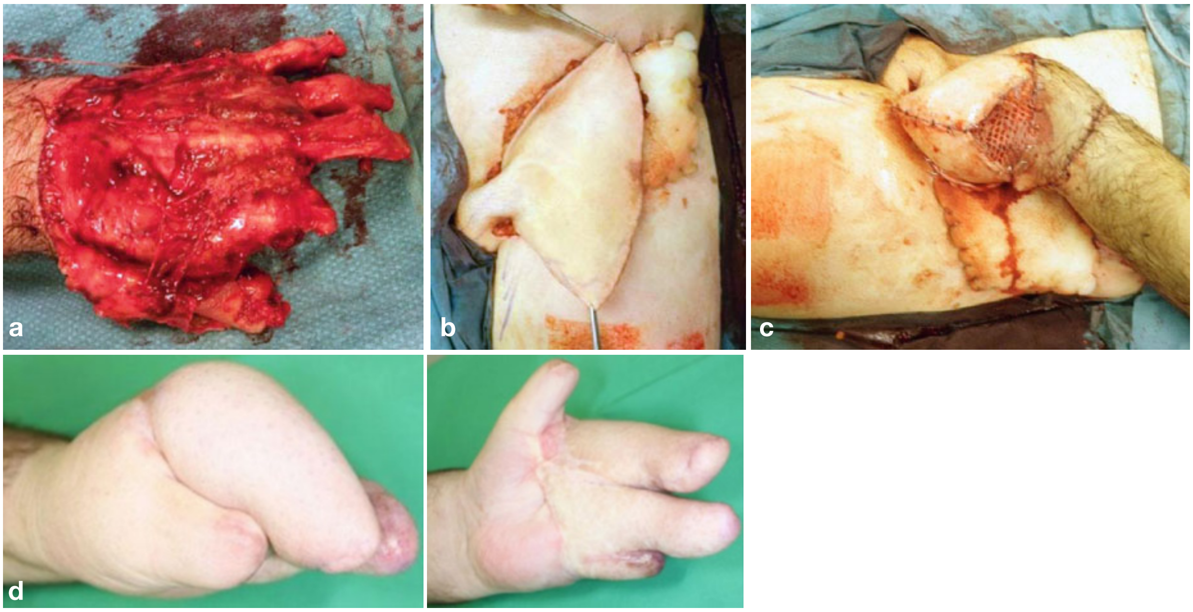

Fig. 14.16 Degloving injury of the hand (**a**); advantages of the groin flap are that it is rapidly and easily harvested (**b**); coverage of the hand with pedicled groin flap and skin graft for closure of the donor site (**c**); result after 3 month and two operation for separating fingers (**d**)

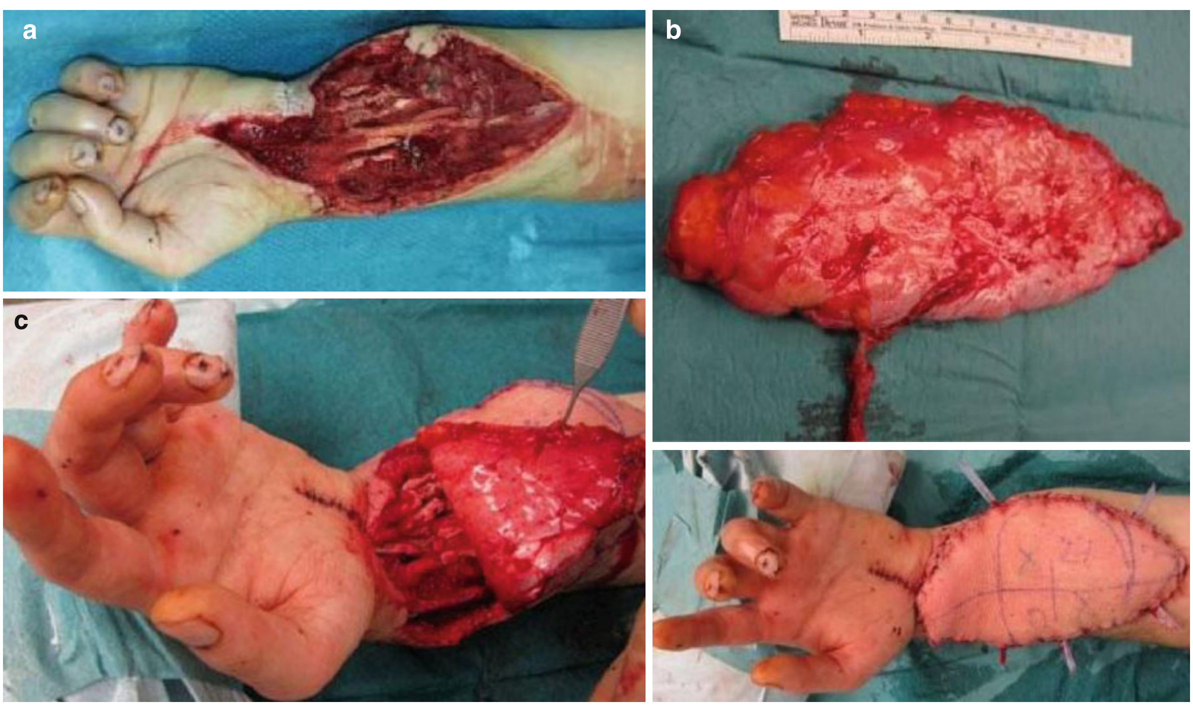

Fig. 14.17 Deep self-inflicted wrist laceration as shown in Fig. 14.5 after tendon and nerve repair (**a**); free anterior lateral thigh flap (ALT) (**b**); Coverage of the forearm defect with the free flap (**c**)

affected limb (no vessel and not more than 25 % of soft tissues intact). Consequently, replantation means restoring a completely separate body part, while revascularization is the restoration of the blood flow in a subtotal amputation.

14.8.2 Indications for Replantation

Absolute indications are: Amputation of the thumb
Amputation of several fingers
Amputation with concomitant serious injury of several fingers
Amputation of the metacarpal
Amputation of wrist/forearm/elbow or upper arm (in sharp amputations and intact amputates)
Amputation injury in children
Relative indications include: Isolated finger in intact neighboring fingers (exception: special function needed, e.g., for a profession)
Single distal phalanx amputation or destroyed MCP or PIP joint
No indication/contraindications are present in case of: Life-threatening additional injury
Improper handling or destruction of amputates (e.g., freezing)
Amputation of the DIP joint/nail root
Incompliance of patient
Multilevel injuries

The indication in favor or against a replantation is often difficult and depends on various factors.

14.8.3 Assessment of the Patient

The decision is based on the history and mechanism of the accident, occupation, age, and smoking-related co-morbidities, and absence of associated injuries. The patient must be informed of opportunities and chances of success of the operation and included as far as possible in the decision-making process for or against replantation. The first requirement is that the patient is able to tolerate surgery over several hours and is not compromised by preexisting conditions or associated injuries. In children, replantation almost always should be attempted. Although the growth of the replanted body may be reduced, the results regarding motion and sensibility are usually much better than in adults. On the other hand, advanced age alone is not a contraindication for replantation; a mentally and physically active patient beyond the age of retirement can equally benefit from a microsurgical reconstruction. It must be remembered, however, that for prolonged and intense physical therapy and occupational therapy, the patient's cooperation and ability to understand is required. The microsurgical reconstruction makes sense if the function is expected to be at least as good as or better than a prosthetic.

14.8.4 Assessment of the Amputate

The suitability of the amputate depends on:

- Ischemia time
- Amputation level
- Amputation type (Guillotine type vs. avulsion or severe contusion)

Clear guillotine-like amputations without joint involvement have a better prognosis for replantation than avulsion or crush mechanisms (e.g., table saw injuries), which complicate the surgical management and reduce the chance of success (Fig. 14.18).

14.8.5 Evaluation of Overall Injury

Due to its functional significance, replantation of the thumb is always desirable in order to achieve maximum length preservation. In case of injury to the palmar neurovascular bundle, the thumb can be revascularized with a long vein graft from the radial artery or the princeps pollicis artery. In multiple finger amputations, a heterotopic replantation of the least injured parts in the best functional position is advisable (e.g., to put the index finger on the thumb stump). Successful replantations of amputations at the metacarpal, wrist, or forearm level are usually functionally better than prosthesis.

If sensibility is sufficient for a protective function, the extrinsic forearm muscles lead to a satisfactory hand function, even if the intrinsic hand function is usually poor. Due to the slow nerve regeneration of about 1 mm per day, and a distance of 40–80 cm, functional return of the intrinsic hand muscles is unrealistic.

Fig. 14.18 Amputate of the index finger by a table saw, hand and radiograph showing a guillotine-like amputation (**a**); assessment of the amputate reveals a severe crush with no opportunity for replantation (**b**)

In macro-replantations, age of the patient, ischemia time (about 4–8 h, depending on cooling) and the suitability of the amputate for replantation represent the main determinants.

A special entity of amputations is ring avulsions of the fingers, which are classified using different systems, most commonly according to Urbaniak.

Classification of ring avulsion injuries according to Urbaniak:

I. Perfusion of the finger distal to the injury intact, simple soft tissue injury or fracture, simple osteosynthesis sufficient.
II. Perfusion disturbed and reconstruction of either arteries or veins required, or both, but no complete amputation
III. Complete avulsion with amputation and fracture in middle and distal phalanx, with avulsion of functional structures (Fig. 14.19).

Third-degree avulsions have the worst prognosis, especially proximal to the PIP joint.

If the amputation is distal to the insertion of the FDS tendon and the PIP joint is intact without further destruction of the proximal phalanx, the replantation may have a more favorable prognosis. Vessels should

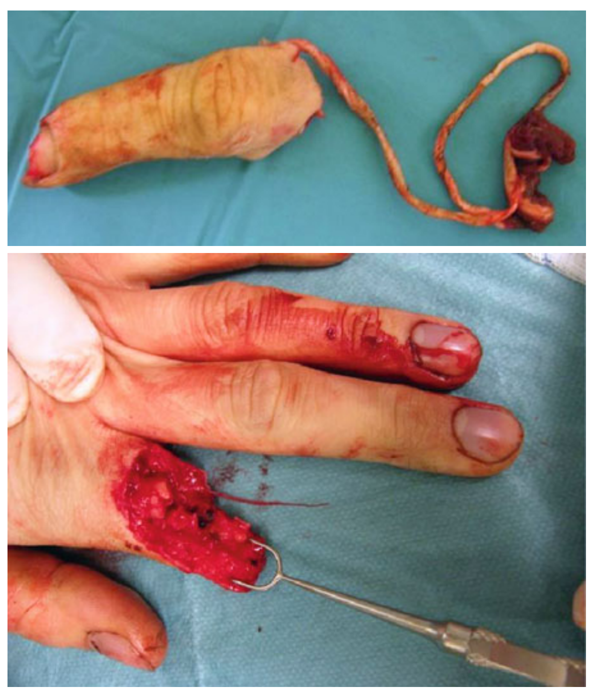

Fig. 14.19 Ring avulsion of the index finger

always be shortened sufficiently and restored by vein grafts.

Ischemia tolerance (cooled at about 4 °C) depends on the soft tissue components:
Without muscles (e.g., finger) 8–12 h up to 24 h
With muscles (e.g., forearm) 4–5 h up to 8 h

14.8.6 Technical Requirements

Instrumental and technical requirements for microsurgical replantation and revascularization include:

- Magnifying loupes (3.5–4.5-fold magnification, working distance of 35–45 cm) for the surgeon and assistant
- Surgical microscope (at least 20-fold magnification), best with two binocular eyepieces, for the surgeon and assistant
- Precision microinstruments with forceps (thickness 0.2–0.3 mm), jeweler forceps and tweezers with coated tips, fine needle holders, microirrigation, and possibly a microdilatator
- Suture material for vessels and nerves (fingers at 10-0, 10-0, and 9-0 in the metacarpal and proximal to the wrist, 8-0), nonresorbable (Ethilon, Prolene, or similar)

Although many plastic surgeons have received microsurgical training, replantation should take place in centers where microsurgical training options exist and such operations are performed regularly.

14.8.7 Transport of Amputates

The appropriate transportation and storage are critical to the success of replantation. Amputates should be recovered at the accident scene and, after careful cleaning, be cooled and transported in a wet compress; they should never be stored in direct contact with ice. Special bags should be used with an inner pouch in which the dry amputated can swim in an outer pouch filled with ice-water. Maceration of the amputate will induce swelling of the vessels and render replantation considerably more difficult or impossible.

14.8.8 The Surgical Management

After an initial X-ray examination of the injured limb and amputate, two members of the replantation team start to clean and prepare the amputate. In amputated fingers, medio-lateral incisions are used to identify and dissect the digital nerves and the accompanying palmar vessels; then the flexor and extensor tendons and dorsal veins. Nerves, arteries, and vessels are marked with micro clips or 9–0 sutures after arteries and veins were rinsed by Liquemin. The veins may be hard to find initially, a spilling of the arteries may be helpful. If the veins cannot be detected, wait until the first arterial anastomosis is accomplished and venous outflow can be seen. Marking of vessels and nerves in the still bloodless surgical field proves helpful and saves time, especially in multiple finger replantations and when, in the advanced stage of the operation, efficiency and patience of the surgeon may be reduced.

After the tendon is identified, the bone is shortened with an oscillating saw. If the PIP joint or DIP joint is destroyed, arthrodesis is performed.

The bony fixation should be performed quickly and without additional injury of the dorsal structures, preferably using K-wire (1.0 or 1.2 mm) and transosseous suture.

A perioperatively plexus catheter for pain and sympathetic management is important.

When the patient reaches the operating room, the second team starts to prepare the proximal stump under loupe magnification and tourniquet, also using medio-lateral incisions to identify and mark the important structures corresponding to the amputate. Finding veins in the fingers requires a subtle preparation, but it is important because venous outflow is critical for success.

Basically, the same procedures apply for micro- as for macro-replantations; although, in the latter case, because of the lower tolerance of ischemic time, restoring perfusion is considered the first priority.

The order of procedures in a replantation is usually:

1. Cleaning and debridement of the soft tissues at stump and amputate
2. Marking tendons, vessels, and nerves
3. Debridement and possible shortening of the bone, joint arthrodesis in functional position if necessary
4. Osteosynthesis (mostly by K-wires)
5. Suture of flexor and extensor tendons
6. Suture of palmar arteries
7. Suture of nerves
8. Suture of dorsal veins
9. Soft tissue closure, possibly only temporarily (e.g., in severe swelling)

14.8.9 Dressing

The dressing is made with loosely laid gauzes and compresses. Constriction by a circular bandage, for example, by drying blood, should never occur. The hand should be well padded and kept warm by generous cotton wrapping. A volar splint in intrinsic plus position may be applied together with a plexus catheter and reduced active mobilization can be started.

14.8.10 Postoperative Management

Important points of the postoperative care are:

- Plexus catheter to control of the sympathetic vasoconstriction and improve circulation for 4–7 days
- Elevation of the arm on a cushion; in case of venous congestion the arm can also be suspended
- If venous drainage if venous drainage is a problem, use of leeches for 3–4 days
- For arterial inflow problems, the hand must be kept slightly lowered

Skin color, finger temperature, skin turgor and capillary refill time (preferably 1–2 s) are useful in assessing the perfusion situation. The perfusion status of the replanted finger or the hand can change suddenly. In order to react quickly, during the first 3–4 days a reliable and regular monitoring must be ensured

14.8.11 Evaluation of Results

The Chen classification evaluates the functional results after replantation in the upper limb:

I. Able to resume previously held employment; range of motion (ROM) exceeds 60 % of normal; complete or nearly complete recovery of sensibility; muscle power of grades 4 and 5
II. Able to resume professional activities; ROM exceeds 40 % of normal; nearly complete sensibility; muscle power of grades 3 and 4
III. Able to lead normal daily life; ROM exceeds 30 % of normal; partial recovery of sensibility; muscle power of grade 3
IV. Almost no useable function in survived limb

14.8.12 Complications

Typical risks after revascularization and replantation include

- Reamputation in case of ischemia or functional disability
- Motion deficits and disorders
- Cold sensitivity, primarily dependent on the type of injury and also possibly in amputation stumps
- Nail growth disorders
- Stump neuroma

14.8.13 Postoperative Treatment, Rehabilitation

Surgical treatment usually includes immobilization with a splint, mostly in neutral position or extension of the wrist, flexion of the MCP joints, extension of the IP joints (intrinsic plus – positioned to minimize contractures). Early intensive physiotherapy is useful to optimize the sliding of the tissue layers. To prevent edema (with the risk of fibrosis caused by lymphatic congestion) limb elevation, drainage, intensive physiotherapy, and occupational therapy are recommended (Fig. 14.20).

Additionally, psychological and social support should be offered after a complex hand injury.

14.8.14 Secondary Operations

Secondary operations include operations requiring postoperative immobilization:

- Bone grafts (Fig. 14.21)
- Corrective/joint reconstructions
- Nerve transplants
- Sensitive reconstructions
- Muscle transpositions / functional muscle transplants
- Soft-tissue reconstruction
- Toe transplants

At a later stage, procedures requiring early mobilization are performed:

- Tenolysis
- Capsulotomies
- Contracture releases

Fig. 14.20 Early intensive physiotherapy with dressing to monitor the perfusion of the free flap (**a**) postoperative result after 6 month of patient shown in Figs. 14.5 and 14.17 (**b**)

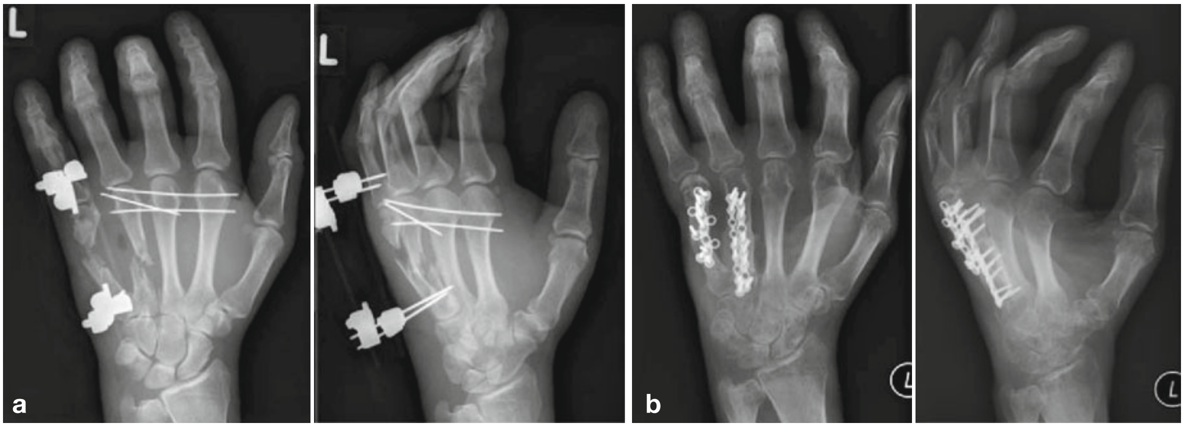

Fig. 14.21 Postoperative radiograph with external fixation after revascularization of ring and small finger as shown in Fig. 14.12 (**a**); change to internal fixation with 2.3 mm dorsal plate and bone graft after 12 weeks (**b**)

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Cervical Spine Injuries

15

Christoph Josten and Jan-Sven Jarvers

15.1 Introduction

The cervical spine is the most flexible part of the spine and protects the upper part of the spinal cord in the transition zone to the static thoracic spine. Furthermore, it has a complex bond to the cranium. The cervical spine realizes a balanced bearing of the relatively big head on the body. In cases of unphysiological application of force and high-velocity trauma, the heavy head acts as a catapult and can lead to both simple and complicated injuries of the ligamentous and bony structures.

Fractures and injuries of the ligaments often show characteristic pattern of injuries regarding the involved structures. Improved examination techniques (computed tomography (CT), magnetic resonance imaging (MRI), angiography) as well as increased diagnostic attention have lead to an awareness of the mechanisms of injuries. This, in combination with advanced operation techniques like navigation or intraoperative three-dimensional (3-D) imaging, have brought forth the operative possibilities with fracture-specific treatments, guaranteeing an early and secure mobilization.

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15.1.1 Initial Measures

Among the first measures for a potentially cervical spine injured patient is the application of a cervical collar to assure temporary immobilization until the patient is brought to a hospital and a diagnosis is made.

15.1.2 Clinical Examination

Patient awareness of pain in a particular region can be a good indicator of the location of injury. The injured segment is identified through local pain after compression, percussion, and pressure. Hematoma or contusion marks can sometimes be seen. With an unconscious patient, deformities or exaggerated gaps of the spinous process can lead to the proper diagnosis.

15.1.3 Neurological Examination

The neurological status is an essential part of the examination. The most frequently used classification regarding the neurological status is that of Frankel:

A No sensitivity or motor function
B Sensitiveness intact, no motor function
C Sensitiveness intact, motor function with development of force <3/5
D Sensitiveness intact, motor function with development of force >3/5
E Normal sensitivity and motor function

The reflex status implies the examination of normal and pathologic reflexes. In the case of a spinal shock, all reflexes may be absent for 24 h after injury. In cases of combined injuries of the spine and cranium, central

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and medullar lesions can be differentiated from the reflex status. The absence of monosynaptic reflexes indicates a lesion of the medulla, whereas their existence suggests a central lesion.

Cervical spine injuries can be classified according to the anatomical region, type of injury and the age of the patient. Regarding the unique anatomy of the atlas (C1) and axis (C2), the cervical spine should be subdivided into the upper (C0–2), the lower (C3–6), and the cervicothoracic transition region.

15.2 Upper Cervical Spine (C0–2)

15.2.1 Anatomy

The upper cervical spine includes two important joints, the atlanto-occipital and the atlantoaxial. In these anatomical structures, the base of the skull, the atlas (C1), the axis (C2), and several stabilizing ligaments are included. The base of the skull consists of the clivus, occipital condyles, and foramen magnum. The stabilizing ligaments are built of the Ligamentum transversum, Ligamenta alaria, and Membrana tectoria. An extreme dimension of mobility – 50 % of rotation as well as flexion and extension in the cervical spine – characterizes this segment. The rotation mainly takes place in the C1/2 joint, whereas flexion and extension mainly are realized between C0 and C1. As with the other mobile joints in humans, these ligaments must allow a considerable degree of motility while at the same time protecting the local neurovascular structures.

The Ligamenta alaria arise from the lateral surface of the Dens axis, insert at the inner surface of the occiput condyles, and reach the medial adjoining rim of the Foramen magnum. The fibers of the Ligamentum transversum atlantis originate from the inner surface of the Massa lateralis, enclose the Dens at its base from posterior, and thereby avoid a sliding of the Dens into the region of the spinal cord.

This stabilization is realized through the posterior and paraspinal musculature. The posterior suboccipital musculature, in particular, ensures sensitive adjustment and stabilization of the head, facilitating a correct function through cerebral nerves of the innervated sense organs. The Musculus rectus capitis posterior minor and major also plays an important role in stabilization. Both the operative dissection as well as the removal of this musculature, or its injury in case of a whiplash, can lead to relevant disorders and should be avoided.

15.2.1.1 Osseous Structures

The three osseous structures that build the upper cervical spine have different sizes and forms. The heavy cranium articulates at only two points with the spine, the condyles, and is fixed with tight ligamentous structures to the spine. The atlas is the smallest bone of the spine and the only one without a regular body or a disc, stabilizing the cranium. It is a part of the anchor mechanism for the Ligamentum transversum. The axis is the major vertebra of the cervical region and the first with posterior facet joints.

Individual fractures and ligamentous injuries distinguish the spectrum of injuries of the occiput, atlas, and axis. Almost 15 % of all cervical spine injuries affect extension. Lateral movements are barely possible. The main stabilizer bar of the atlantoaxial joint is the Ligamentum transversum, with a size of up to 10 mm, approximately double the size of all other joints. Therefore, fusions of C1 and C2 lead to an immense loss of rotation, which can be compensated in young patients; whereas, in older patients, it potentially becomes symptomatic because of arthrotic changes.

The occipitocervical joint (C0/C1) realizes motility of almost 20° for flexion/extension and, therefore, contributes 50 % of the motility for certain movements of a normal cervical spine. At the same time, only marginal movement for rotation and lateral motion is possible (about 5–10°). Because of the absence of a disc between C0/C1 as well as C1/C2, this region does not have a possibility for cushion and observes a high rate of compression fractures at the osseous site, while distraction-dislocation injuries occur in the ligamentous parts. Different measurement techniques, such as the Chamberlain line or the Powers quotient, aim at detecting these injuries (atlanto-occipital dissociation).

The atlantoaxial joint (C1/C2) mainly realizes rotational movements with a dimension of almost 45° for both sites and only 10° for flexion and extension. Translation and distraction movements of the atlantoaxial joint are, in general, limited through a tight complex of ligaments, radiologically measured with the atlantodental interval. A gap of more than 3 mm in adults and 5 mm in children can be declared as pathological.

15.2.1.2 Vascular Situation

The Arteria vertebralis and spacious vein plexus, as well as the first and second cranial nerve, are other important structures in this region. The Arteria vertebralis arises out of the Arteria subclavia and enters the spine in the area of the sixth cervical vertebra (in some patients it enters in the fifth or seventh vertebra) and takes this course until the second cervical vertebra.

The foramen transversum of the atlas is located more laterally; therefore, the arteria vertebralis takes a lateral bow, through which the arteria achieves enough motility for the circular motion. Thereafter, the arteria continues posterior around the Massa lateralis in order to attain anatomically the Sulcus arteria vertebralis of the posterior atlas bow through the Membrana tectoria into the cerebrum. There, it coalesces with the collateral A. vertebralis to the A. basilaris. Many anatomical variations have been described, including the important Arteria inferior posterior crebelli (PICA), which rises extracranially. The spacious vene plexus lays ventral of the C1 and C2, bows close to the dura, and can provoke severe bleeding after injuries.

15.2.2 Indications

15.2.2.1 Operative vs. Conservative Treatment

The conservative treatment of injuries of the upper cervical spine with immobilizing casts, ortheses, or the halo fixator has given way to operative procedures. Improved diagnostics, correct analyses of fracture mechanisms, and modern operation techniques with limiting osteosyntheses have effected great advances. In cases of stable fractures, functional treatment should be preferred; a short immobilization with a soft collar is legitimate treatment. It there is a question of whether operative or conservative treatment should be performed, the "decision triad of the spine" is to be consulted:

1. Are there neurological symptoms?
2. Is it a stable or unstable situation?
3. How robust is the constitution and the dimension of the actual or prospective deformity?

Neurology

Neurological symptomatology in injuries of the upper cervical spine is seldom seen. Compressions and especially distraction have an effect on the spinal cord and also on the important structure of the medulla oblongata. Injuries of the craniocervical transition zone can provoke neurological forms of pareses, paresthesia, pain, and the Brown-Sequard syndrome. Although the paraspinal space in the middle and lower cervical spine area is only a few millimeters, it is rather spacious in the craniocervical region and finds enough backup capacity in case of compression.

The question of the presence of a neurological lesion can, in case of an awake patient, be answered easily through a specific physical examination; this is more difficult in polytraumatized, intubated patients. The emergent operative treatment of injuries in the upper cervical spine is, except for neurological deficits or the case of a monotrauma, rather rare. Although certainly early treatment should be aspired to in these injuries, competence of the surgeon as well as exact preoperative planning are essential for a successful result. Any surgical procedure in this region requires an extraordinarily experienced surgeon and should only be performed in centers.

Stable vs. Unstable Situations

The dimension of instability can be determined with several radiological issues (e.g., the Chamberlain line, lateral mass displacement according to Spence, etc. [5, 31]). Mainly osseous injuries recover in a secondary stabilization; predominantly ligamentous injuries mostly remain permanently unstable. The following radiological criteria exist for certain planes:

In the lateral plane, it is the enlargement of the distance from the posterior wall of the atlas to the anterior surface of the Dens axis of more than 3–4 mm.

In the frontal plane, an overlapping of the Massa lateralis of the atlas with more than 6–7 mm above the lateral margin of the axis

Deformity

Only few criteria are postulated for this issue. The possibilities of compensation for osseous stable healed dislocations vary widely. Extreme tilts of the Dens axis as well as luxations between the joints can remain and lead to disorders that must be corrected operatively.

15.2.3 Injuries

In the upper cervical spine, the following entities are described:

1. Fractures of the condylus occipitalis (OCF)
2. Atlanto-occipital dislocations
3. Fractures of the atlas
4. Atlantoaxial instabilities (AAD)
5. Fractures of the axis

15.2.3.1 Fractures of the Condylus Occipitalis (OCF)

Epidemiology

Fractures of the OCF only play a small role in the literature.

Classification

In the classification of Anderson and Montesano [2], three types are discerned (Fig. 15.1):

Type 1: Impacted condyle fractures

Type 2: Condyle fractures with fractures of the subcranium

Type 3: Sprain fracture of one or both condyles

The advantage of this classification is its therapy-decisive character, as types 1 and 2 can be seen as stable and should be healed with a cervical collar for 6 weeks. In the case of type 2 injuries, an additive injury of the cerebral nerves VII–XII should be considered. The difficulty of unstable fractures of type 3 can be seen in the not-rare appearance of an atlanto-occipital instability.

Diagnosis

With the routine use of the thin-slice CT, diagnosis is made more frequently. Although axial CT images are useful in assessing the presence of occipital condyle fractures, they do not usually enable visualization of the entire condyle (Fig. 15.1).

In the event of compression fractures, fragments can impinge into the foramen magnum. Sprain fractures can reach the region of the clivus and cause clinical symptomatic hemorrhage. Osseous tears of the condyles mainly impress saucer-type in the course of the Ligg. alaria, adjusted medio-caudally. In general, these injuries should be treated conservatively, even though distinctive atlanto-occipital instabilities are not accordable with life. For a reliable diagnostic apart from the axial, coronal slices of the thin-slice CT are particularly useful. The slice thickness should not exceed 1–2 mm. For ligmantous visualization, MRI is essential.

Therapy

The therapy of the above-described injuries should be decided with regard to the overall situation of the mostly severe injured patient. Unstable type 3 fractures require either an occipitocervical fusion or can be treated with immobilization via a halo fixator for 8–12 weeks. Complications include anterior luxations of a fractured condyle with dislocation around or into the foramen magnum. Aside from these rare complications, the prognosis of the OCF is rather good, although painful constrictions, especially of head joint function, can remain.

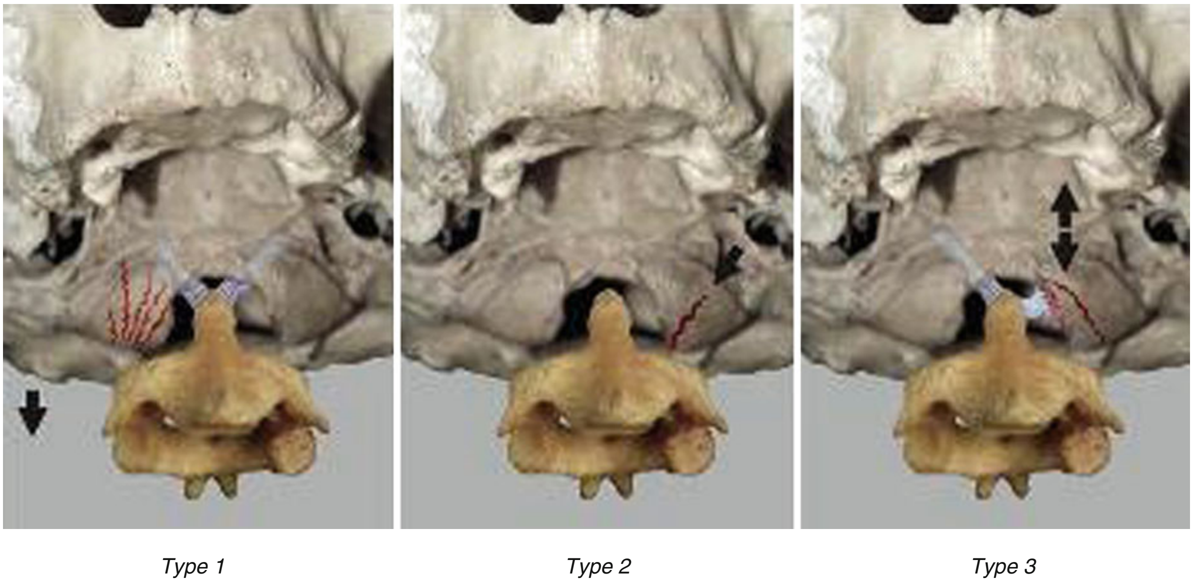

Fig. 15.1 In the classification of Anderson and Montesano [2], three types are discerned: *Type 1* Impacted condyle fractures, *Type 2* Condyle fractures with fractures of the subcranium, *Type 3* Sprain fracture of one or both condyles from [21]

Ligamentic Instabilities of the Upper Cervical Spine

The traumatic ligamentic instabilities of the upper cervical spine are seldom seen and can be subdivided into four groups:

- Occipitocervical dislocation
- Translatoric atlantoaxial instability
- Axial atlantoaxial instability
- Rotatoric atlantoaxial instability

15.2.3.2 Atlanto-occipital Dislocations

Epidemiology

Atlanto-occipital dislocations are a rarity and represent profound and life-threatening injuries. In most cases, shearing motion in terms of translation is causative for these lesions. A rupture of the membrana tectoria is the consequence. High-energy trauma most often accounts for the mechanism of injury. A distraction with hyperextension and flexion is common, usually combined with a rotation component. Because of the relative ligamentous insufficiency in infancy and the additive horizontal course of the bearing area C0/C1, children are significantly more frequently affected. A second accumulation can be seen in pedestrians struck by a car.

Classification

According to Harris, there are three types of occipitocervical dislocations with regard to the direction of the head luxation [15] (Fig. 15.2):

Type 1: Anterior dislocation – the most common form, unstable sagittal or combined sagittal and axial

Type 2: Posterior dislocation – a rarity

Type 3: Axial decompression – the most unstable form, global instability or complete separation of the head from the cervical spine

Diagnostics

Dislocation can often be seen in conventional X-ray images, but the CT scan is the gold standard, especially to detect additive injuries like condyle fractures, type 3 fractures according to Anderson and Montesano, or type 1 fractures of the dens. Functional images can be useful to evaluate ligamentous injuries, and MRI is useful here as well to show any neurological damage.

Several methods are described to quantify the spatial relationship between the occiput, atlas, and axis. The most common in the setting of trauma are the basion-dental interval (BDI) and the basion-posterior axial line interval (BAI), originally described by Harris et al. [15]. In their studies, Harris and colleagues measured the BAI and BDI on lateral radiographs of 400 healthy adults; the BAI and BDI did not exceed 12 mm in 98 %. Today, the BDI and BAI have come to be known as "Harris measurements," or, more descriptively, as the "rule of twelve" (Fig. 15.3).

Ratio according to Powers: The line of the posterior border of the anterior arc of the atlas to the posterior border of the foramen magnum on the one hand or the posterior border of the pars basilaris to the anterior part of the posterior arc of the atlas (Fig. 15.4) can provide helpful information and lead to faster orientation.

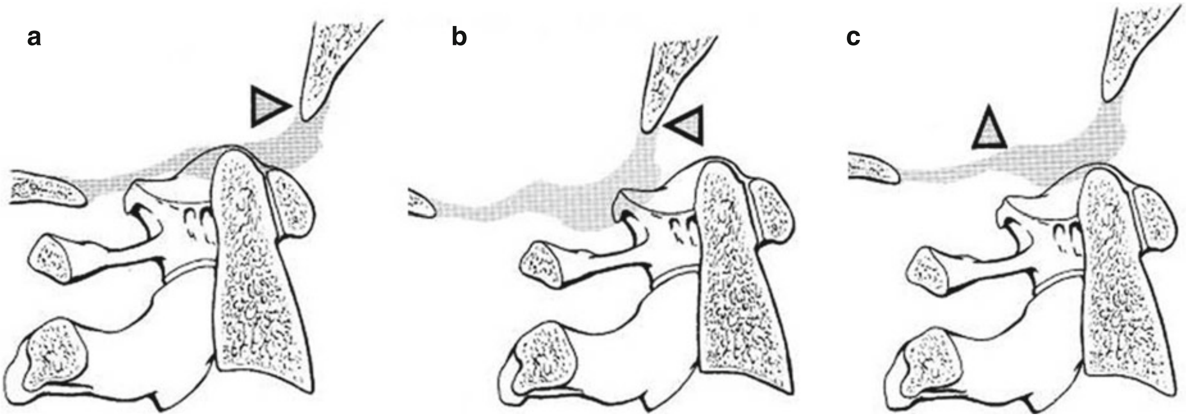

Fig. 15.2 Atlanto-occipital dislocations according to Harris. (**a**) Type 1: Anterior dislocation – the most common form, unstable sagittal or combined sagittal and axial; (**b**) Type 2: Posterior dislocation – a rarity; (**c**) Type 3: Axial decompression – the most unstable form, global instability or complete separation of the head from the cervical spine

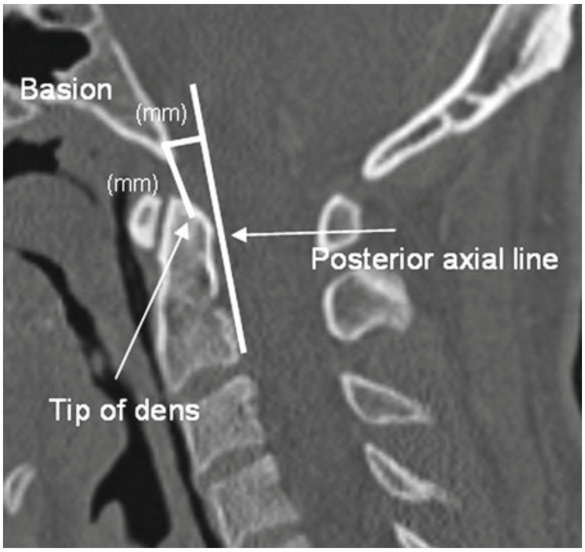

Fig. 15.3 Measurement technique for the BDI and BAIs. "Rule of the twelve" Harris measurement: The most inferior and posterior aspect of the basion is marked as well as the superior tip of the odontoid process (*arrow*). The distance between these two points (BDI) is measured in millimeters: a value >12 mm is highly suggestive of occipitoatlantal dissociation. A vertical line is drawn along the posterior vertebral border of the C2 body (*arrow*). This line should extend superiorly, just past the level of the foramen magnum. A perpendicular line is drawn from this line to the basion mark. This distance is then measured in millimeters (BAI). A value>12 mm should be considered indicative of an anterior occipitoatlantal dissociation

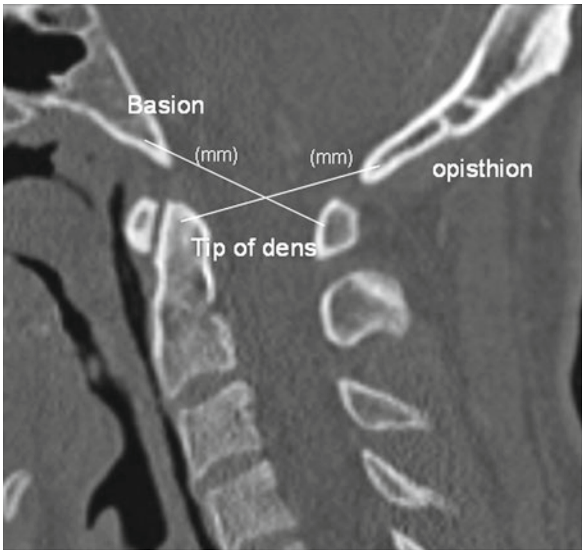

Fig. 15.4 Powers ratio

Functional examination under fluoroscopic guidance can discover hidden instabilities; again, a thin-slice CT scan is the standard, completed with 3-D reconstructions. Additionally, an MRI should be performed, when the patient has been stabilized, to diagnose a contusion of the medulla. Injured patients may show no or only marginal neurological symptoms, though the injury is highly unstable. Apart from osseous injuries, ligamentous lesions have a notable impact. In particular, the craniocervical ligaments (Membrana tinctoria, Lig. transversum, Lig. alarium and apicale) are of importance for the stability of the craniocervical transition zone [9], along with the epidural amplifying ligaments. The lateral craniocervical ligaments (Lig. nuchae, flavum, and the posterior and anterior atlanto-occipital ligament) have only a minor effect on stability, as does the atlantoaxial membrane [34]. In case of an atlanto-occipital dislocation (AOD), one or more ligaments are usually ruptured. Neurological symptoms are caused by traumatic lesions of the Medulla oblongata or the cranial nerves. As additive injuries, subarachnoid hematoma have been described [6], along with injuries of the A. carotis, A. vertebralis, and the anterior spinal artery. Therefore, an angio CT scan should be included in the diagnostic algorithm.

Therapy

Excessive traction should be avoided, especially during the primary treatment, as more dislocation can lead to iatrogenic neurological symptoms. The patient should be monitored during a reduction process. The maneuver starts with controlled traction and ends with axial compression to minimize dislocation or translation of the segment C0/C1 [26]. In case of an emergent therapy, a closed reduction with a temporary immobilization with a halo fixator, then a planned posterior spondylodesis with C0–C1/C2 (C3) should be performed. If the patient survives the injury, a loss of motility, measured up to 23° in the sagittal plane and 50° in rotation, can occur [18]. Intensive physiotherapy is essential for recovery of the function of the head joints after consolidation of the fractures (Fig. 15.5).

Translatoric Atlantoaxial Instability

Epidemiology

Translatoric atlantoaxial injuries are seldom seen, as the Ligamentum atlantis brings more resistance towards the incoming forces than the Dens axis.

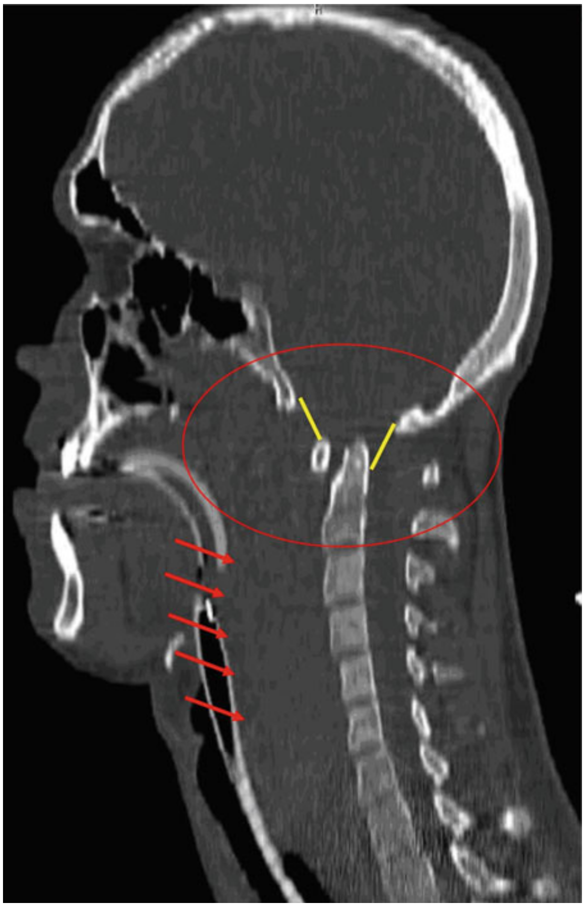

Fig. 15.5 Example of anterior dislocation: 22-year-old patient after car accident, death 3 h after accident. Note the soft tissue swelling (*red arrows*) and the reduced BDI (*yellow line*). The *red oval* shape marks the injury zone

Classification

These injuries occur through a rupture or an osseous tear of the Lig. transversum atlantis [20] and are classified regarding to De la Caffinière [7] with consideration of the anterior atlantodental interval (AADI), with measurements normally up to 3 mm (Fig. 15.6).

Diagnostics

The instability can sometimes be seen in conventional X-rays, whereas osseous tears are detected by CT scan. Arbitrative for the diagnostic findings are the functional images, showing the ligamentic instability. Another helpful measurement technique is shown in Fig. 15.7.

Therapy

Differentiation between osseous tears and interligamentic ruptures is of importance in therapy. In the case of osseous tears, the grade of dislocation is crucial. For marginal dislocations with remaining osseous contact, conservative treatment can be chosen with a hard cervical collar for 6 weeks. Larger dislocations with only a poor chance of osseous reunion should be treated with atlantoaxial fusion, even in younger patients, as atlantoaxial instability and arthrosis can occur through a relative elongation. As the interligamentic ruptures also show no tendency for healing, atlantoaxial fusion is recommended.

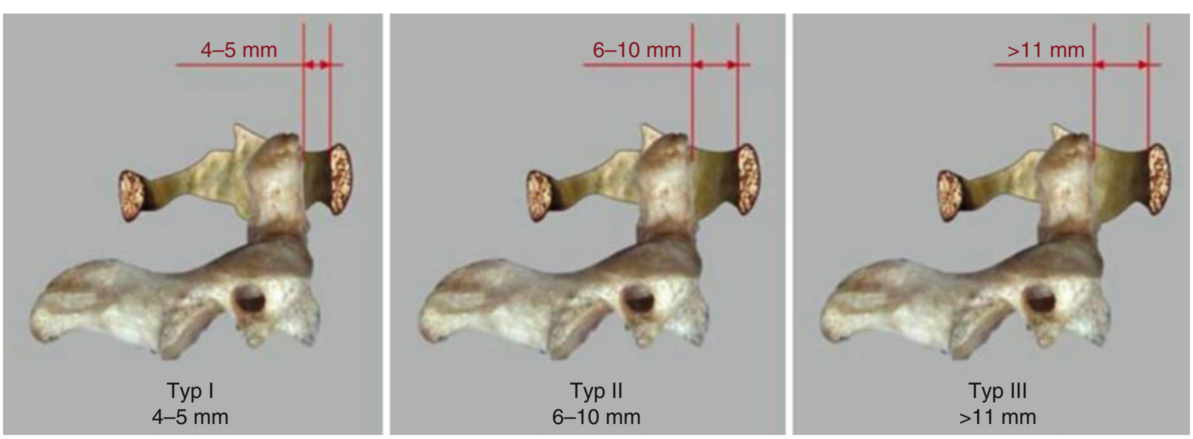

Fig. 15.6 Classification according to De la Caffinière [20]

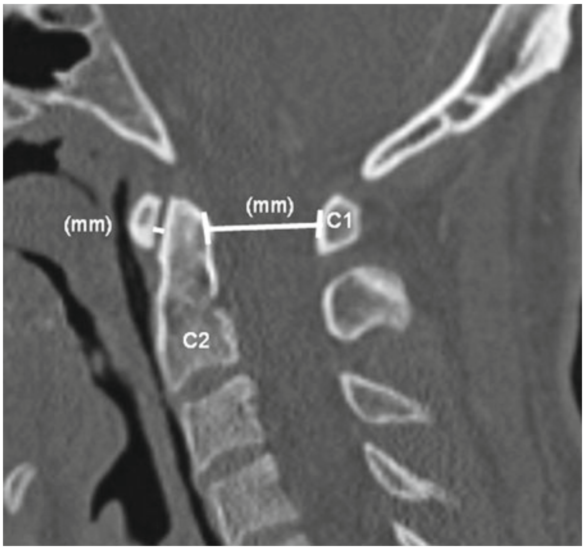

Fig. 15.7 The ADI (atlanto dens interval, normal 3 mm) and the PADI (posterior atlanto dens interval, normal 12 mm): The craniocaudal midpoint of the anterior ring of C1 is marked. A line parallel to the ring of C1 is drawn from this point toward the odontoid process. The distance between the C1 mark and intersection with the anterior aspect of the odontoid process is measured in millimeters

Axial Atlantoaxial Instability

Epidemiology

Axial atlantoaxial instability is seldom seen. It occurs through axial translation between atlas and axis. A rupture of the atlantoaxial (Lig. supra- and intraspinale, Lig. flavum) and occipitocervical ligaments (Fasciculi longitudinalis, Ligg. alaria, Lig. apicis dentis) takes place. This injury is linked with occipitocervical instabilities.

Classification

The classification still is heterogeneous. Incomplete forms are distinguished from the complete form with or without translation [32].

Diagnostics

In conventional X-rays, the distinctive instability can be seen. The CT scan detects osseoligamentous tears. Again, functional images can prove the ligamentous injury using axial force. In the MRI, the ligamentous and neurological lesions can be seen.

Therapy

The therapy for atlantoaxial instabilities should be performed with a closed reduction with temporary fixation with a halo fixator, followed by definite therapy consisting of a occipitoatlantoaxial spondylodesis. Although initial images present dramatic pictures with the suspicion of disruption of neurological structures, patients mainly show only a few neurological symptoms.

Rotatoric Atlantoaxial Instability

Epidemiology

Traumatic rotatoric instabilities are seldom seen. A rotatoric instability occurs mainly through the interligamenteric rupture or a osseous tear of the Ligg. alaria. Pathophysiologically crucial is the ligamentic lesion between the condyle of the occiput and the dens axis, which permits an excessive rotation of occiput and atlas on the axis. Especially in children, a rotational atlantoaxial malposition, even without a rupture of the Ligg. alaria, can occur as an atlantoaxial subluxation.

Classification

According to Fielding and Hawkins [12], four types of rotational instability occur (Fig. 15.7):

Type I: Rotational instability with unilateral translation without ventral sliding of the atlas intact L. transversum.

Type II: Ventral and unilateral dislocation between C1 and C2, enlargement of the atlantodental distance 3–5 mm, possible rupture of the Lig. transversum in adults.

Type III: Atlantodental distance >5 mm, ruptured Lig. transversum, subluxation of both facet joints in the ventral direction.

Type IV: Rotational dislocation with shifting of the atlas in the dorsal direction in case of a destructed dens axis.

Diagnostics

Instability can sometimes be seen with the decentric located dens axis. The CT shows osseous tears of the ligaments as well as condyle fractures type 3 according to Anderson and Montesano or type-1 fractures of the dens. The MRI shows the ligamentic structures, though a functional assessment of the Lig. alaria is not possible. As conventional functional images, also in anteroposterior (a.p.) view, are difficult to interpret in this injury, functional rotational CT is recommended for the diagnosis of a rotational instability [3, 27]. In case of a deviation of the sides of more than 5°,

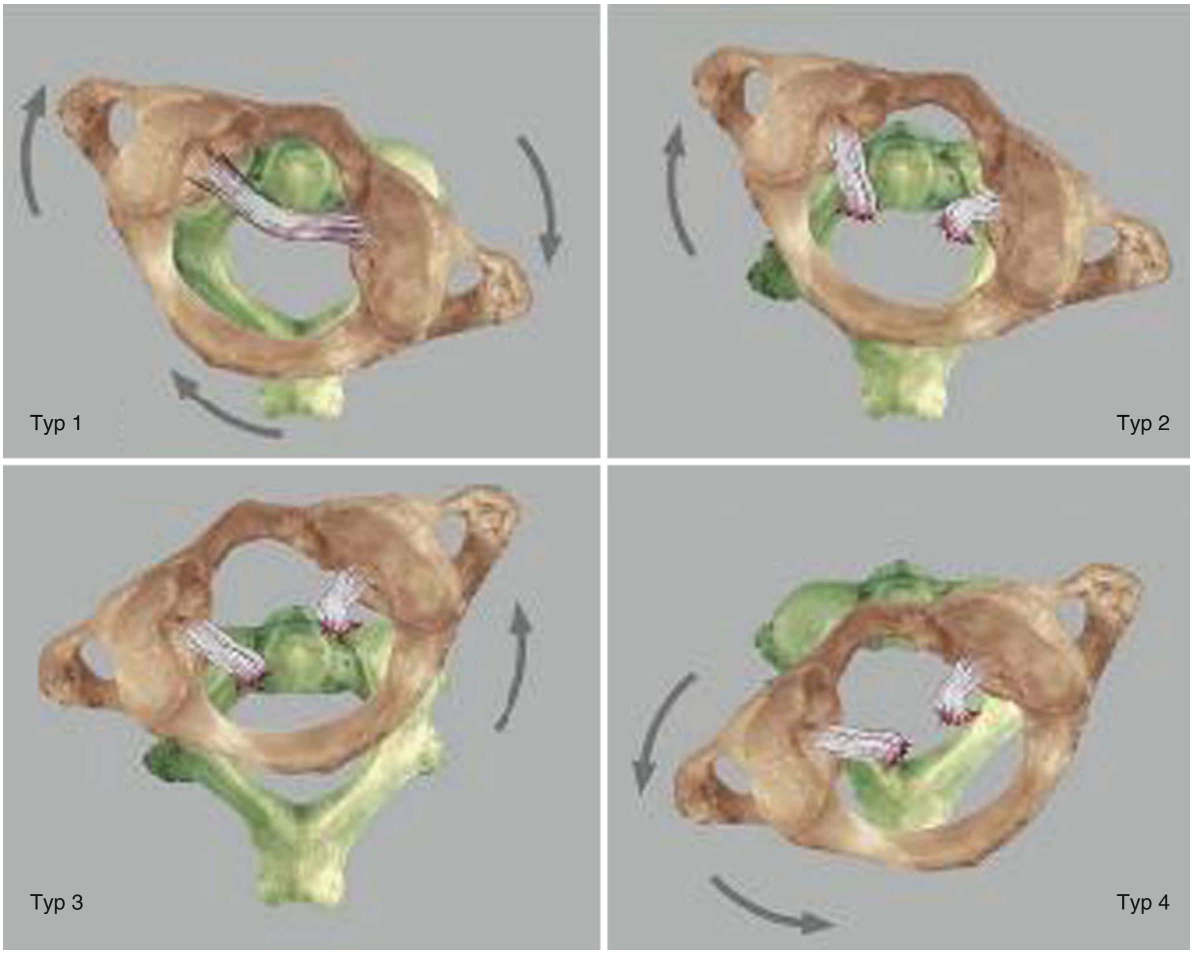

Fig. 15.8 Rotational instability

a rupture of the Ligg. alaria can be assumed. Figure 15.8 shows the most recommended measurement technique [17, 22] (Fig. 15.9).

Therapy

These fractures occur through rotation of the axis adverse the atlas around the longitude axle of the body and are more frequent in children. As a sufficient healing with conservative treatment cannot be expected [4], the therapy results in a spondylodesis C1/C2, in general from posterior. In the case of type-III lesions with ruptured Lig. transversum, a posterior stabilization C1/C2, for example, according to Magerl, should be chosen. Finally, it is important to underline the possibility of an iatrogenic vertical dissociation through tension during the reduction process.

15.2.3.3 Atlas Fractures

Epidemiology

Fractures of C1 seldom occur but are more frequent than the above-mentioned injuries. In the literature, the incidence amounts to 2–13 % of all cervical and 1.3 % of all spine injuries [29]. The Jefferson fracture only represents 2 % of all cervical spine injuries, though it accounts for two-thirds of the atlas fractures [14].

Classification

Jefferson distinguished four different fracture types in 1920:

Type I: Isolated bow fractures
Type II: Combined fractures of the anterior and posterior atlas bow
Type III: Fracture of the massa lateralis
Type IV: Fracture of the processus transversus

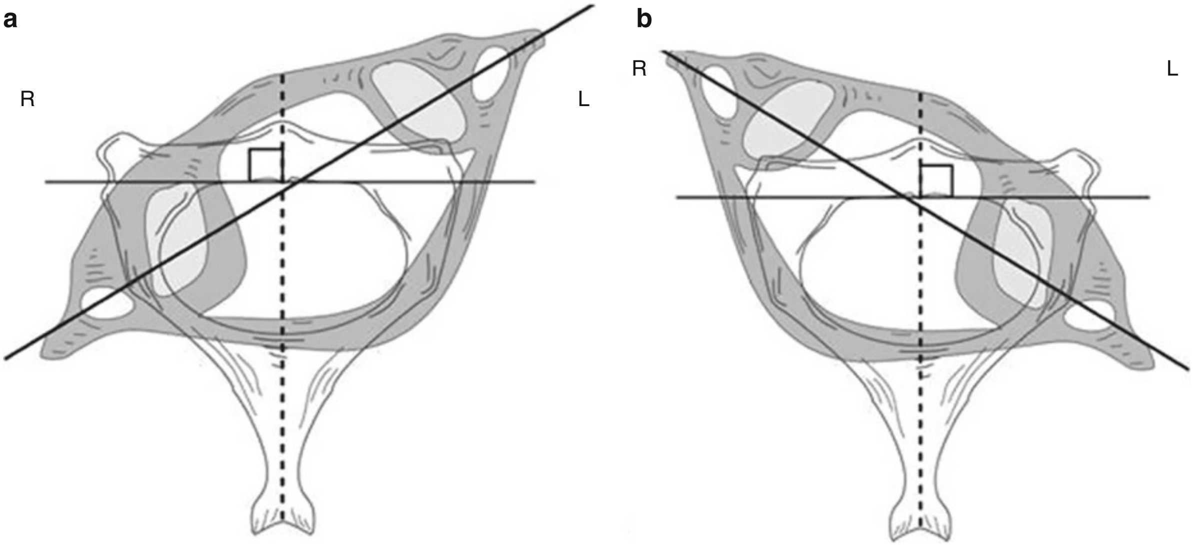

Fig. 15.9 Measurement of *right* (*R*) (**a**) and *left* (*L*) (**b**) atlantoaxial rotation. For optimal measuring, the CT gantry angle should be aligned along the transverse plane of the upper cervical vertebrae. An axial CT slice at the level of the C2 body and C1 ring are then obtained. An anteroposterior line is drawn from the midpoint of the C2 body to the center of the spinous process. A line perpendicular to this line is drawn along the posterior C2 vertebral body. On the best axial slice of C1, the midpoints of the transverse (vertebral artery) foramens are marked, and a line is drawn between them. The angulation between these two lines represents the degree of static atlantoaxial rotatory deformity (subluxation). By convention, the side (*right* or *left*) toward which the atlas (head) points is considered the side of the rotation [5]

Today, the classification according to Gehweiler has proved its value:

Type I: Isolated fractures of the anterior atlas bow
Type II: Isolated fractures of the posterior atlas bow
Type III: Combined fracture of the anterior and posterior atlas bow (Jefferson fracture)
Type IV: Isolated fractures of the massa lateralis
Type V: Fracture of the processus transversus (Fig. 15.10)

Isolated fractures of the atlas occur through indirect impact of force, as there is a relatively good protection through the soft tissue. The most frequent reasons are traffic accidents and falls [30]. In case of an isolated fracture, the patient suffers from suboccipital head and neck pain, possibly linked with sensitive deficits in the region of the N. occipitalis major, but injuries with a combination of other injuries of the spine, mainly a fracture of the axis, are more often seen. Accompanying lesions and thromboses of the A. vertebralis occur, especially in posterior bow fractures. These injuries are generally diagnosed with a CT scan.

In case of the type-IIIb injuries, the differentiation of the lesion of the Ligamentum transversum is important. Dickmann [8] subdivides two main types of injuries: the interligamenteric rupture and the osseous tear. The interligamentous rupture (type I) is distinguished in a central (type Ia) and a lesion near the Massa lateralis (type Ib). The osseous tear of the Ligamentum transversum atlantis (type II) is subdivided into an isolated osseous tear (type IIa) and an osseous tear with a fracture of the Massa lateralis (type IIb), according to a Gehweiler type-IV fracture (Fig. 15.11).

Diagnostics

Atlas fractures often can be recognized in conventional X-rays the. Lee et al. [23] used an open-mouth view to measure displacement of C1 lateral mass fractures (Fig. 15.12); 6.9 mm is the critical amount of total displacement necessary to disrupt the transverse ligament. This consideration may be obviated using calibrated axial and coronally reconstructed CT images; as for further evaluation of the atlas rings' integrity, a CT is oblique. In case of dislocation of the massa lateralis without an indication of an osseous tear of the Lig. transversum, a diagnostic MRI is recommended. In case of a seldom-seen type-V injury, an angio MRI (or angio CT) of the A. vertebralis is oblique to exclude injury of the artery in the foramen of the proc. transversus.

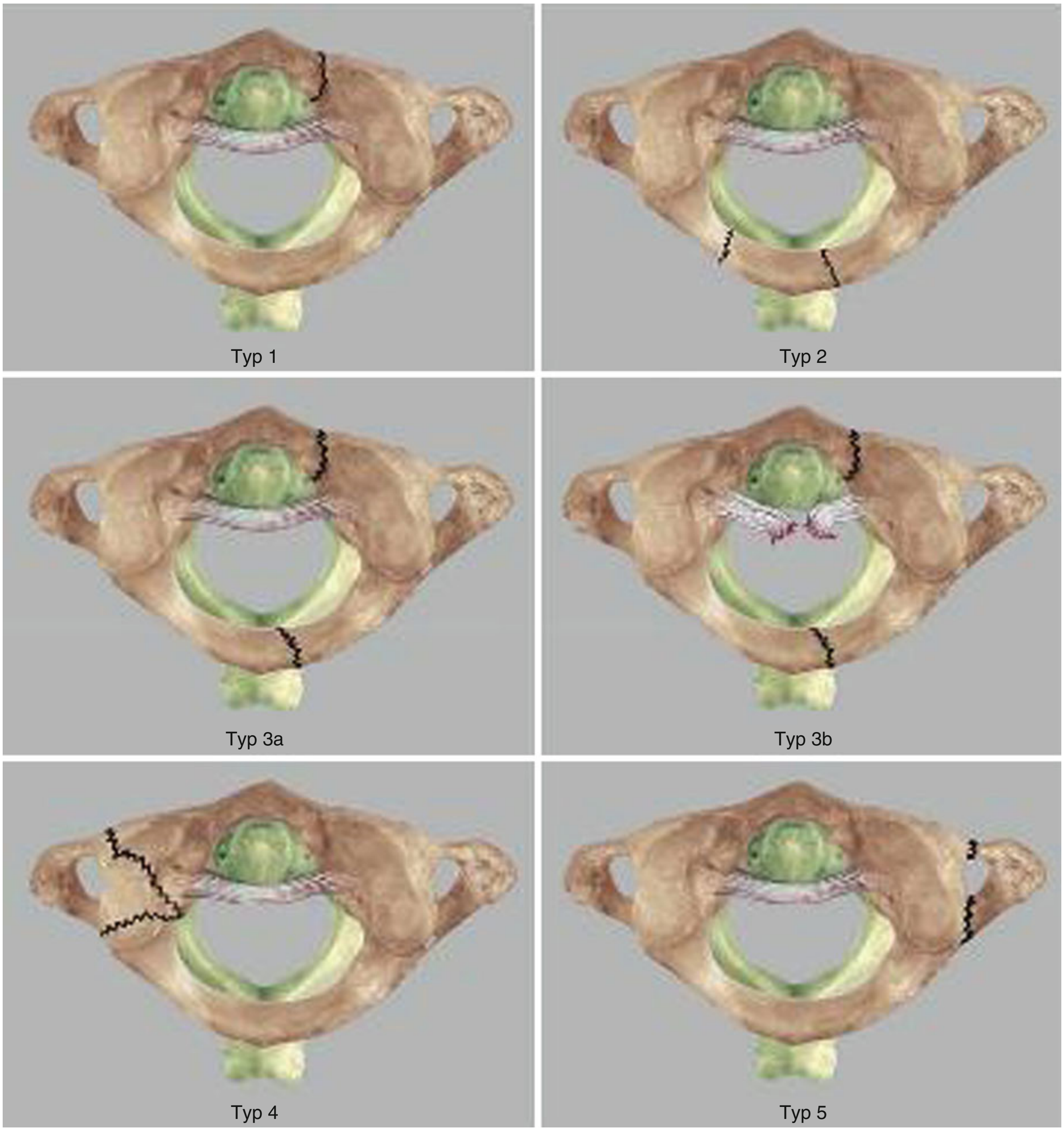

Fig. 15.10 Classification according to Gehweiler (From [21])

Therapy

Atlas fractures can be treated with an immobilization in a rigid cervical collar for 6 weeks. In case of dislocated type-IV fractures with predominant incongruity of the occipitocervical or atlantoaxial joints, an attempt with a halo fixator for 6 weeks should be tried to prevent an arthrosis. The reduction is realized through longitudinal traction and should be controlled through a CT. In case of severe dislocation, an occipitoatlantal spondylodesis can be discussed.

Dislocated type-IIIa injuries can be treated with a halo fixator; in some cases conservative treatment with a semi-rigid Philadelphia orthesis is also possible. If the reduction dislocates, an osteosynthesis of the atlas is recommended [21].

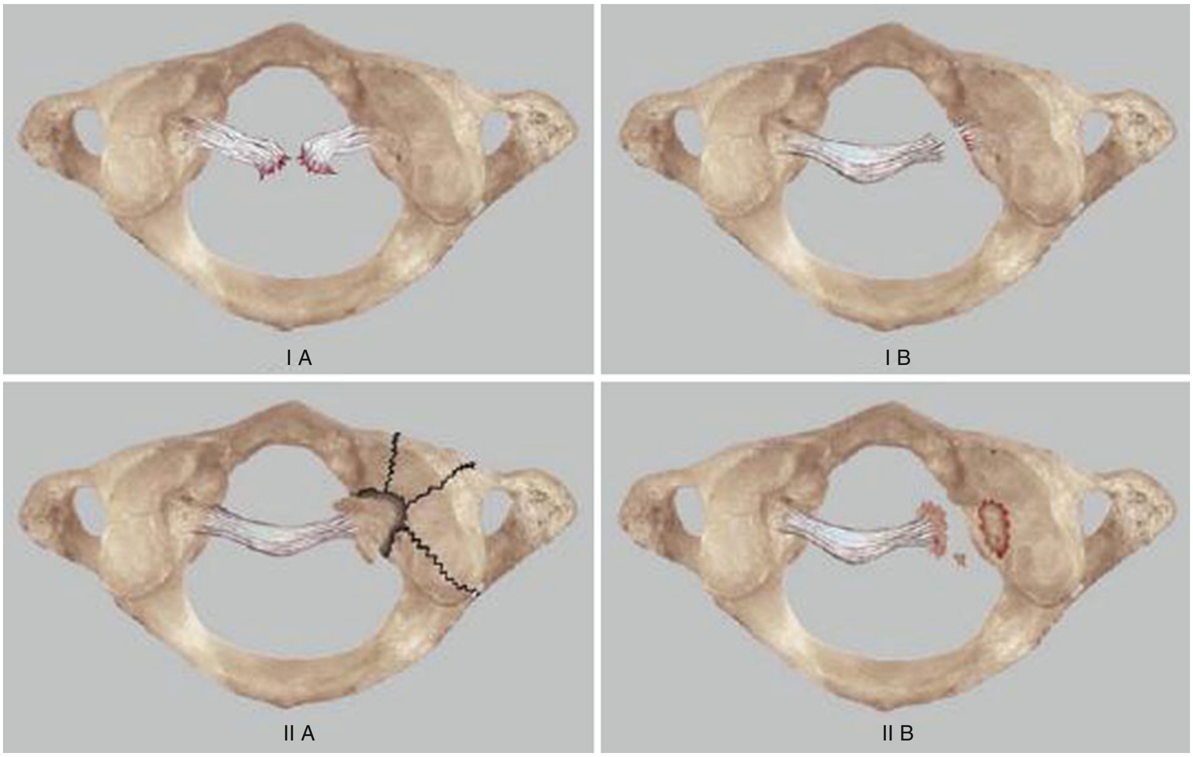

Fig. 15.11 Classification according to Dickmann: interligamentous rupture forms [21]

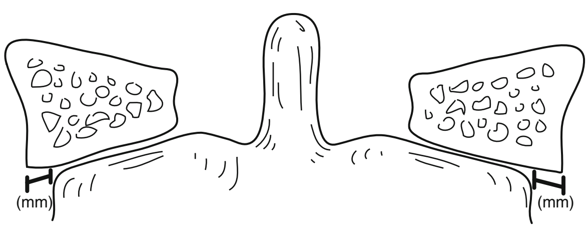

Fig. 15.12 Vertical lines are drawn along the most lateral aspect of the bone of the C1 and C2 articular processes. The transverse distance between them is then measured in millimeters. These are then added to calculate the total lateral mass displacement (From [5])

In case of a lesion of the Lig. transversum atlantis (Dickmann type I) linked with an unstable type-IIIb fracture, a potentially segmental instability exists. Therefore, an atlantoaxial spondylodesis is advised, in some cases even an occipitocervical fusion (Figs. 15.13 and 15.14). In case of unstable type-IIIb fractures with few dislocated osseous tears, isolated stabilization of the atlas can be performed with the advantage of retaining mobility of the cervical spine. Alternatively, atlantoaxial stability according to Goel/Harms without accompanying spondylodesis can be performed, although here removal of the screws must be accomplished for the liberation of this segment. In general, the surgeon must be aware that initial rotation movements almost exclusively occur in the segment C1/C2. In case of fusion of C1/2, the rotation must be accomplished through other segments, which are anatomically not created therefore. Thus, occipitocervical fusions are standing adverse to those techniques, which try to adhere the function following direct reduction [22]. Anterior or posterior transarticular fusions for this fracture entity are the subject of controversy as they impair the lateral atlantoaxial joints and can be the cause of secondary arthrosis.

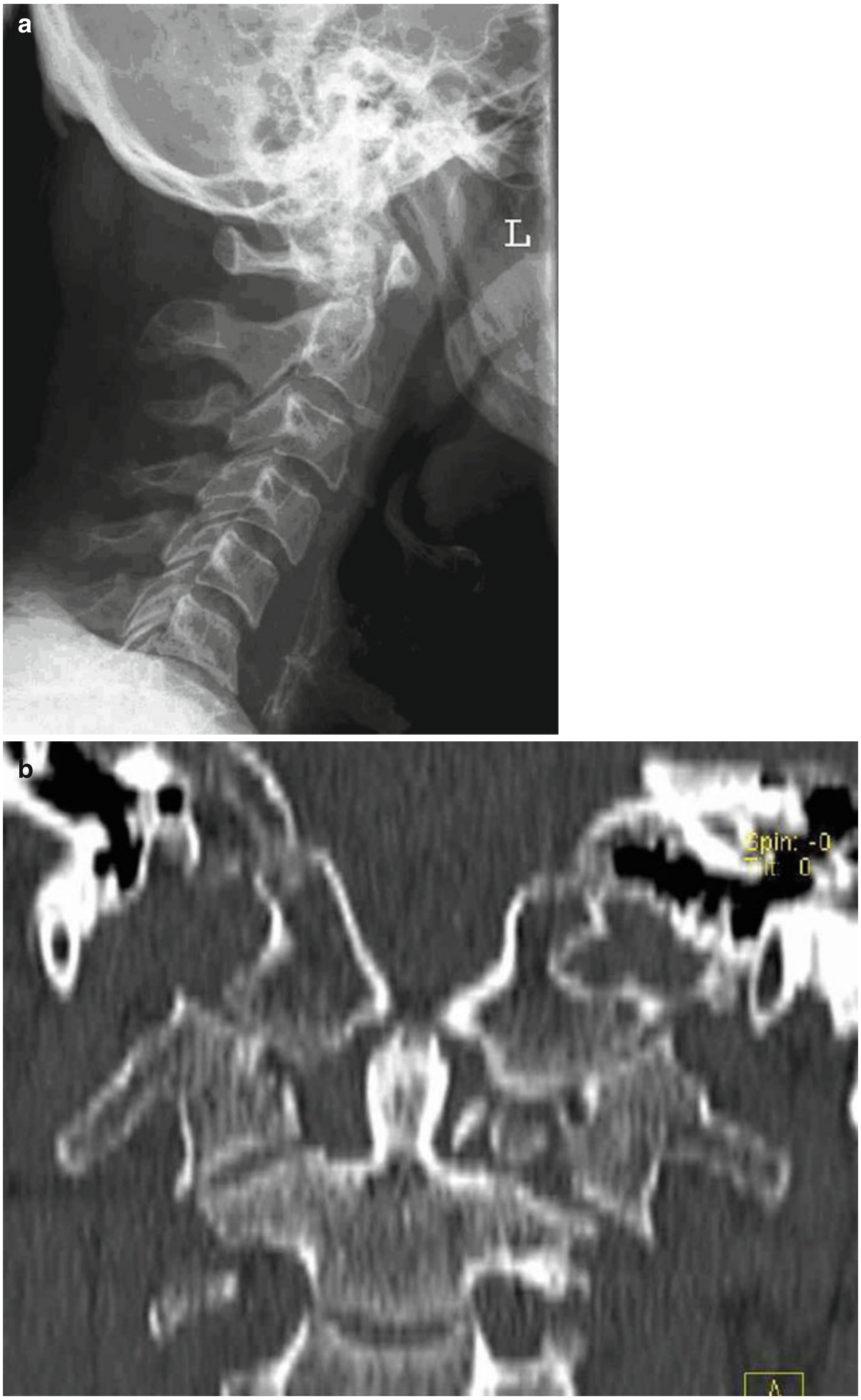

Fig. 15.13 Fifty-two-year-old patient with a Gehweiler type-III fracture, preoperative X-ray, CT, and postoperative X-rays of the posterior C0–C3 stabilization

Fig. 15.13 (continued)

In elderly patients, symptomatic occipitocervical or atlantoaxial arthrosis in consequence of a Gehweiler type-III or -IV fracture develops rather slowly and, therefore, can forego reduction in a halo fixator. Here, the treatment can be accomplished through a rigid cervical orthesis. As the tendency for osseous healing in older patients is rather poor, this treatment should be reserved for younger patients. In older patients with type-IIIb injuries linked with an osseous tear of the Lig. transversum atlantis, a definitive atlantoaxial stabilization is recommended [21, 22] (Figs. 15.13 v 15.14).

15.2.3.4 Fractures of the Axis

Epidemiology

Odontoid fractures are frequent and represent 7–19 % of acute cervical fractures [13] and 71 % of atlantoaxial fractures [24]. Even though traumatic fractures often occur in younger patients, caused by high-energy trauma, older people are increasingly affected, mainly through simple falls on the head. Therefore, standardized X-rays of head, dens, and cervical spine are recommend in older people after a fall on the head.

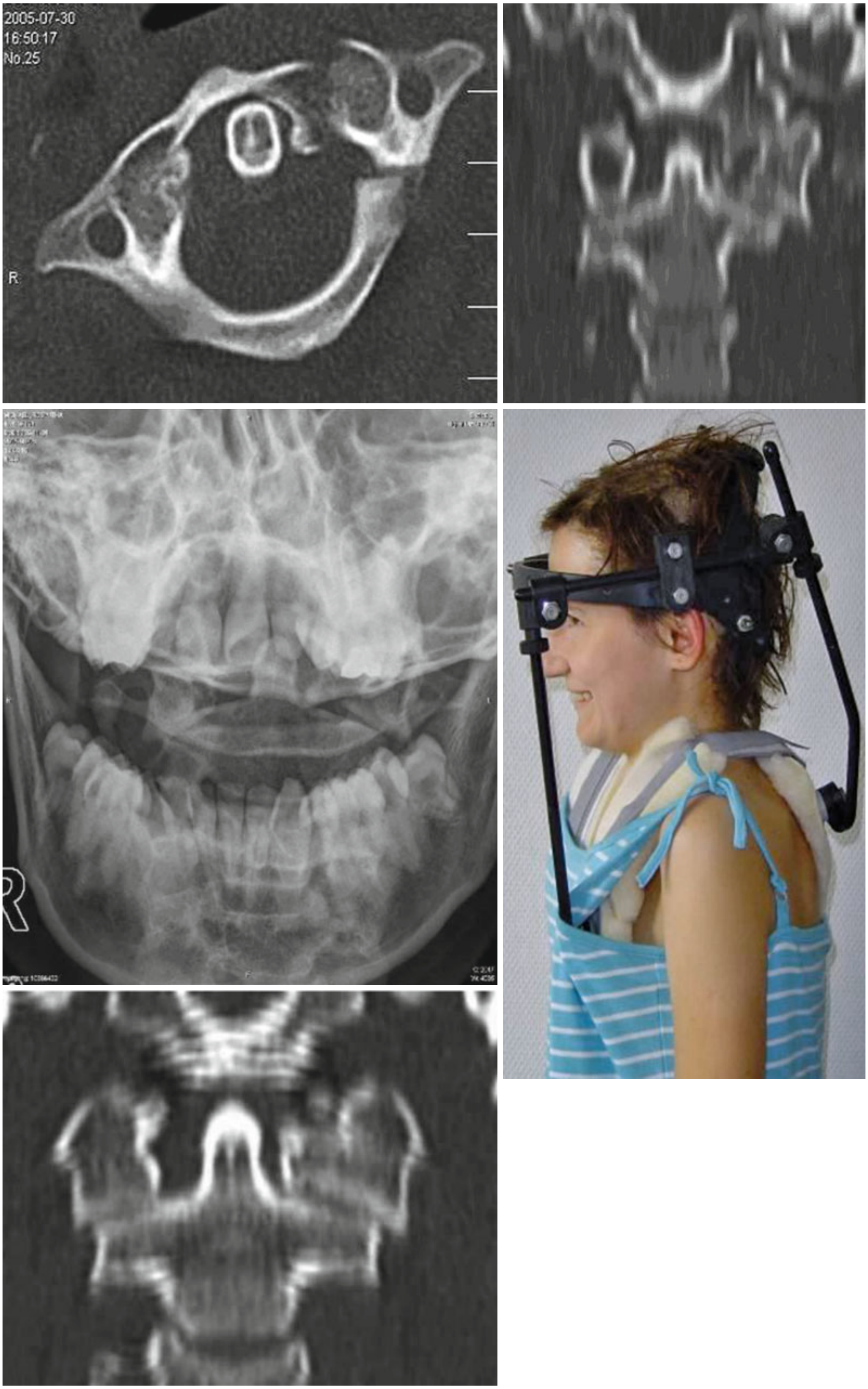

Fig. 15.14 Twenty-year-old patient with a Jefferson fracture, treated with halo fixator, CT 1 year after accident

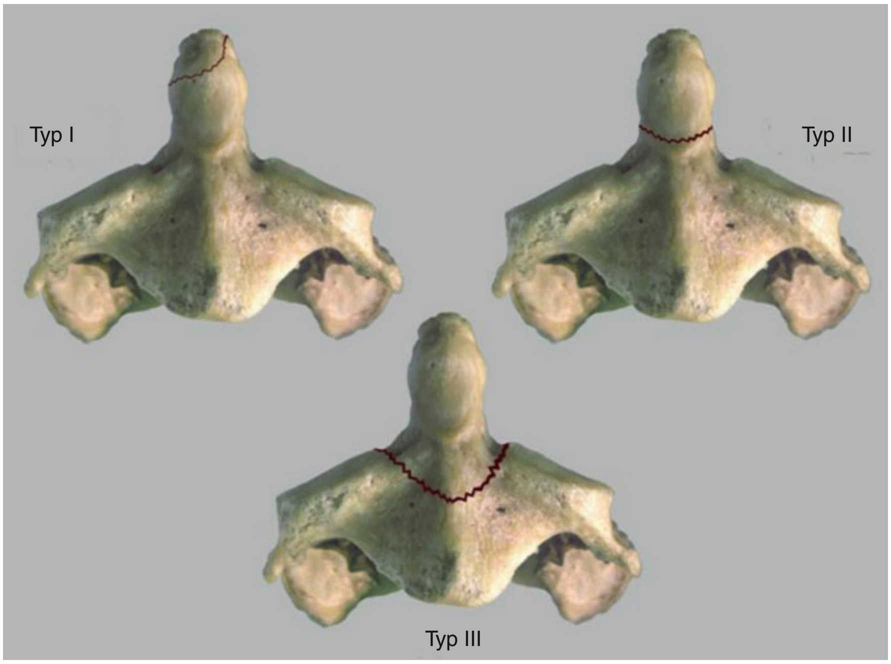

Fig. 15.15 Classification according to Anderson and D'Alonso

Classification
The most common classification is that of Anderson and D'Alonso, subdividing three fracture types:

Type I: Fracture through the tip of the odontoid process (above the level of the transverse ligament)

Type II: Fracture through the base of the neck of the odontoid process

Type III: Fracture extends into the body of C2 and continues through one or both of the articular processes (Fig. 15.15)

The mechanism of the injury is a combination of vertical compression and horizontal shear. For the type-III fracture, a hyperextension is mainly accountable, whereas type-II lesions are caused by an anterolateral shear [28]. Additive injuries relatively often appear locally in the region of the posterior atlas bow or more rarely in the area of the anterior bow of the axis. Neurological deficits often are observed, especially if the dens is dislocated in the posterior direction into the spinal canal. In case of type-III injuries, which include the foramina of the A. vertebralis, traumatic ruptures or closures are possible.

Diagnosis
Apart from lateral imaging, open-mouth radiography according to Sandberg should be standard. Suspicion of such an injury should lead to performance of a thin-slice CT scan with sagittal reconstructions. Additionally, functional images can be taken to prove instability, though these must be performed carefully and under monitoring. The literature reports respiratory problems during the acute management of dislocated type-II fractures [16].

Type-I Fractures
These fractures are relatively rare and normally do not influence the atlantoaxial stability. They are treated conservatively with a collar for 6–10 weeks.

Type-II Fractures
Epidemiology
The dens fracture type II is the most frequent and unstable form. The mechanism of injury extension injuries are subdivided from flexion injuries. With the more frequent extension fracture, the apex of the dens is dislocated towards posterior, whereas it is pulled towards ventral in case of flexion fractures.

Therapy
Type-II fractures that are not dislocated can be treated conservatively when they show no instability in the functional radiological examination. In the other cases

of type-II fractures, the injuries should not be treated conservatively, mainly because of the rate of pseudarthroses. In general, the classic ventral screw fixation is the chosen therapy. The indication for operation can also be measured at the degree of dislocation. Greene et al. [13] regards to a dislocation degree of 6 mm and could proof, that in case of a conservative treatment of type-II fractures with a dislocation ≥ 6 mm the nonunion rate determines 86 % and was significantly lower in the conservatively treated type-II fractures with <6 mm (18 %). As morphological criteria for the decision process, the rate of dislocation, the tilting of the dens, and the diastasis between the fragments can be considered. The standard therapy is the anterior lag screw osteosynthesis (Fig. 15.16), but there are several issues to be taken into account.

If the fracture line proceeds dorsocranial to ventrocaudal (type III according to the subclassification

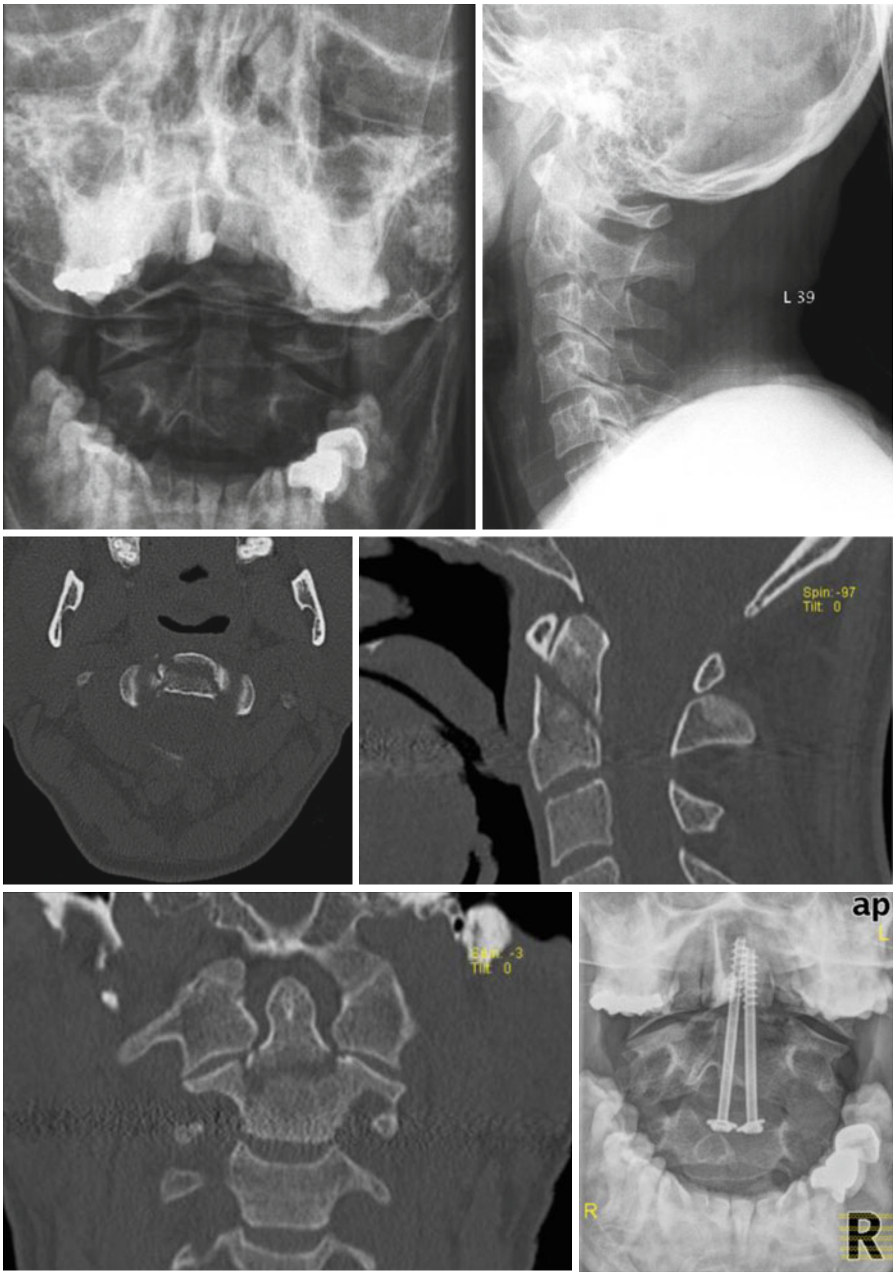

Fig. 15.16 Forty-six-year-old patient after fall on his head. Type-II fracture according to Anderson/D'Alonso, preoperative X-rays and CT, operative treatment with two anterior lag screws, postoperative X-rays

Fig. 15.16 (continued)

of Eysel and Roosen, Figs. 15.17 and 15.18) [11], a large demolition zone, progredient osteoporosis, or anatomical circumstances occur, a classic anterior stabilization may be impossible. In these cases, an atlantoaxial stabilization can be performed, in young patients possibly without spondylodesis, to remove the osteosynthesis after fracture consolidation. Here, the atlantoaxial stabilization regarding Goel/Harms has proved its value, in elder patients the posterior atlantoaxial stabilization according to Magerl or the transarticular atlantoaxial anterior stabilization can be accomplished, especially in older people with additive injuries in the upper cervical spine.

Here, a new fracture entity is described: the "unhappy triad of C1/2." This is defined as a cranial odontoid fracture of the dens, an additive fracture of the anterior or posterior bow of the atlas (Gehweiler type I or II), and a preexisting arthrosis of C1/2. Here, the ATS (anterior transarticular C1/2 stabilization) offers a gentler procedure for geriatric patients via the well-known anterior approach of Smith-Peterson. Based on the diameter of the odontoid process, one or two screws can be placed additively (Fig. 15.19).

Type-III Fractures

These fractures can be seen as stable, mainly because of the large bearing area of cancellous bone. If stable in functional images, they can be treated with a Philadelphia orthesis for 10–12 weeks. According to Müller and Muhr [28], a closed reduction with immobilization with a halo fixator should be accomplished in case of a dislocation >4 mm. Operative treatment can be necessary; here, the anterior or posterior C1/2 screw fixation can be performed because the classic anterior screw fixation is made impossible caused by the diagonal course of the fracture.

Complications

Epidemiology

As mentioned earlier, the dens pseudarthrosis is not seldom, especially in type-II fractures. The main reasons for pseudarthoses are deficits of perfusion, followed by necrosis of the bone, instability, and diastasis of the fragments. An unstable pseudarthrosis can lead to death because of compression of the brainstem.

Diagnosis

The diagnosis can be detected either by an instability in functional images or in a CT.

Therapy

In general, operative treatment is indicated. A secure procedure here is posterior transarticular screw fixation according to Magerl [25], but anterior transarticular C1/2 screw placement can also achieve sufficient stabilization.

15.2.3.5 Traumatic Spondylolisthesis of the Axis (Hangman's Fracture)

Epidemiology

The traumatic spondylolisthesis of the axis is caused by hyperextension-distraction trauma. Apart from that, flexion and compression with rotational movements due to traffic accidents are mechanisms for this injury. The incidence is reported at 15–20 % of all cervical injuries [13]. Because of the relation to this mechanism to a deadly luxation of the second cervical vertebra in the context of the hanging process, this injury is also called the "hangman's fractureand was first described by Bouvier in 1843 and Houghton in 1866.

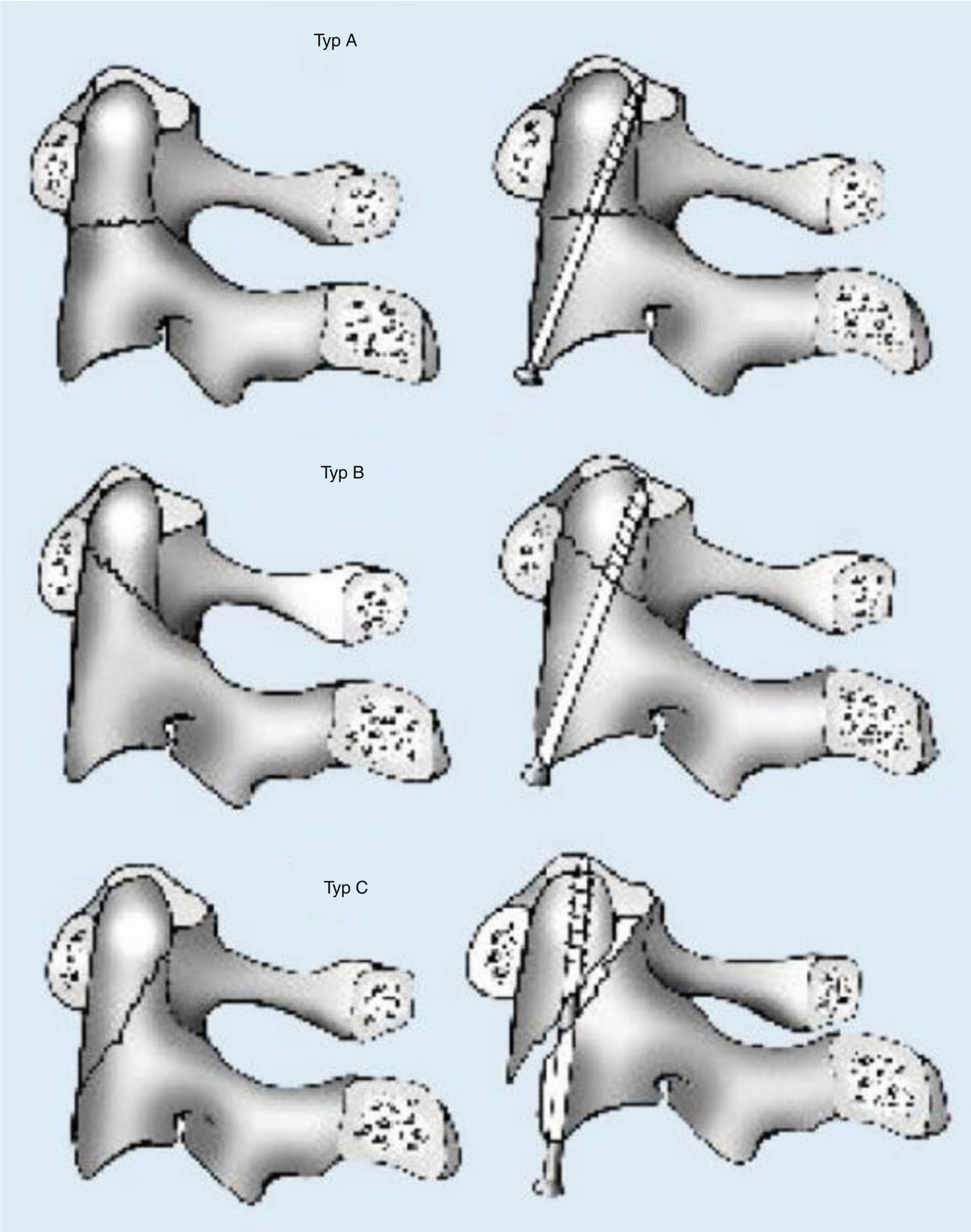

Fig. 15.17 Subclassification according to Eysel and Rosen for type-II fractures

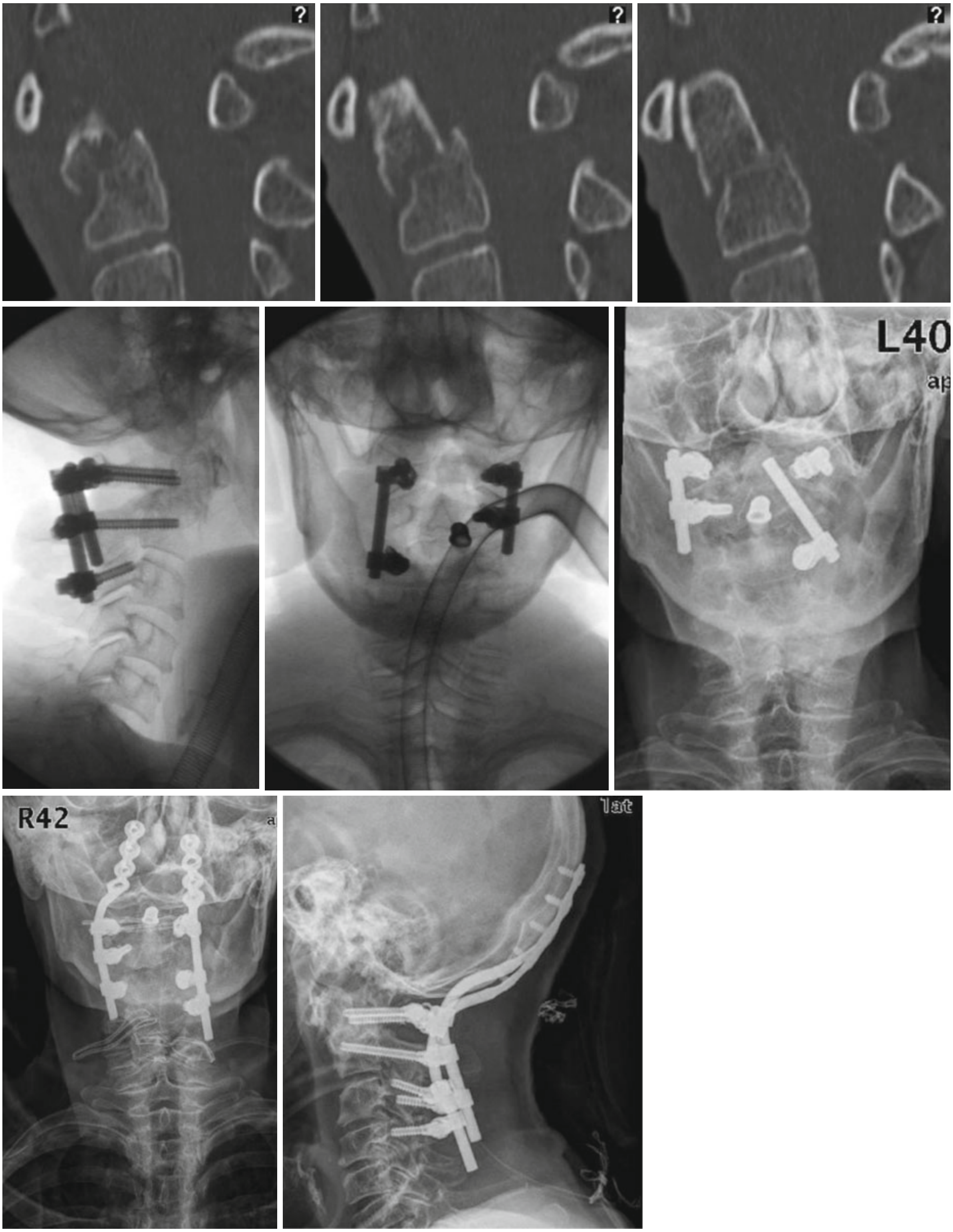

Fig. 15.18 Seventy-four-year-old patient after fall on her head. Atypical odontoid fracture type II according to Anderson/D'Alonso, type B according to Eysel/Rosen. After posterior stabilization, loosening of the stabilization, revision, and C0–4 stabilization

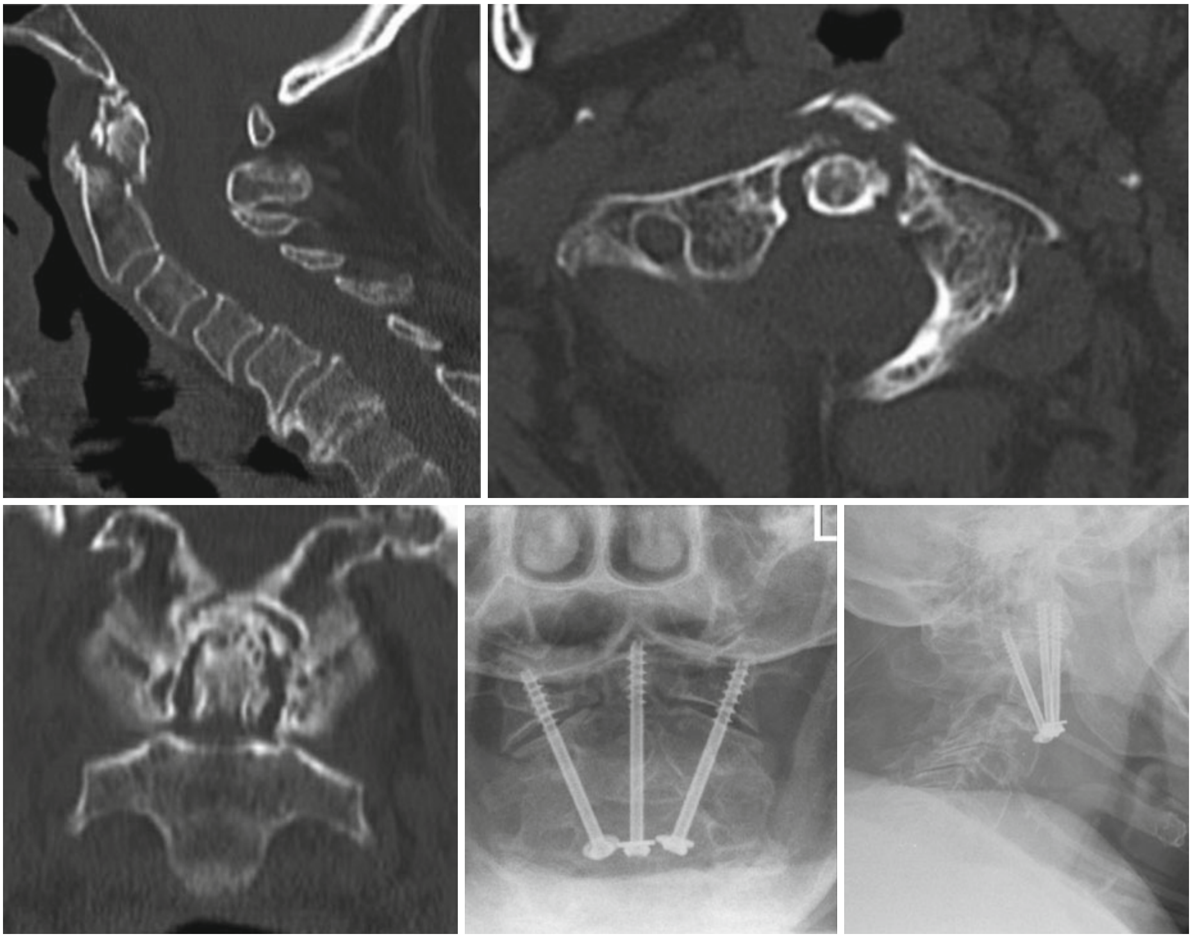

Fig. 15.19 Unhappy triad of C1/2: cranial odontoid fracture of the dens, an additive fracture of the anterior or posterior bow of the atlas (Gehweiler type I), and a preexisting arthrosis of C1/2. Postoperative images with the anterior transarticular stabilization of C1/2

Classification

The most common classification is that of Effendi [10]:

Type I: Not dislocated fracture with intact disc C2/3

Type II: Fracture with lesion of the disc C2/3. Ventral dislocation of the vertebral body C2, flexion-/extension position of the vertebral body

Type III: Additive luxation of the facet joints C2/3

Josten developed his own classification [19]. Thus, a fracture with participation of the anterior longitudinal ligament is described as type III. Type IV stands for a stucked luxation of the facet joints.

Diagnostics

In general, the fracture can be diagnosed sufficiently with conventional X-rays in a.p. and lateral views, as the fracture line normally proceeds through the bow of the second cervical vertebra. Detailed information is given by the CT, as participations of the joints, deformities, intra-articular fracture lines as well as diastasis can be revealed. Because of the anatomical closeness, the A. vertebralis can be injured as well. We therefore recommend an angio-CT/MRI. Other additive injuries appear as combined injuries of the upper cervical spine, and neurological symptoms can often be found.

Therapy

Usually, traumatic spondylolisthesis is not a life-threatening injury. An exact diagnosis is mandatory as well as a differentiated therapy. The correct decision about therapy (operative vs. conservative), including the technically demanding operative procedures, should be determined by an experienced surgeon. Operative treatment is indicated in cases of instability, whereas stable situations can be treated with a Philadelphia orthesis for 6–8 weeks. The treatment of unstable fractures conforms to the ventral degree of dislocation. If it is measured at 3–4 mm and the patient is cooperative, a conservative treatment can be chosen.

According to Josten, immobilization with a halo fixator is recommended for 12 weeks in case of translation of 4 mm because of the assumed damage to the disc. In case of a ruptured Ligamentum longitudinal, intercorporal spondylodesis is recommended. Type-III and IV injuries should be reduced with a halo fixator. If this is not possible, an open reduction has to be performed, prior from posterior direction, then an anterior spondylodesis should be accomplished. Alternatively, screw fixation according to Judet can provide the needed stability.

15.2.4 Lower Cervical Spine (C3–6), Cervicothoracic Transition C7/Th1

Epidemiology

In general, the subaxial spine accounts the majority of cervical injuries, making up about 65 % of fractures and >75 % of all dislocations. Despite a large amount of experience, the classification remains controversial.

Classification

Because of the consistent morphology of the vertebra of C3-T1, the ABC classification for the three-column model of Magerl [25] is commonly used. The instability accelerates in main groups from A to C and in the subgroups from 1 to 3. Type-A injuries occur through compression. Impaction fractures (A1) only show marginal deformations and can be seen as stable. Sagittal and dislocated anterior split fractures are unstable, as is the case for all burst fractures.

Type A: Vertebral body compression
- A1: Impaction fractures
- A2: Split fractures
- A3: Burst fractures

The mechanism for type-B injuries is distraction and flexion or extension. Transligamental flexion or distraction injuries (B1) are unstable and often present a posterior rupture of the ligamental structures. Transosseous flexion-distraction injuries are seldom seen and show a fracture course through the two posterior columns with a separation of in the pars interarticularis of the facet joints. The posterior ligaments remain uninjured, however, the situation is unstable. Hyperextension injuries (type 3) are primary ruptures of the anterior column and are highly unstable.

Type B: Anterior and posterior element injury with distraction
- B1: Posterior disruption predominantly ligamentous
- B1: Posterior disruption predominantly osseous
- B3: Anterior disruption through the disc.

Type C injuries occur through torsion. The result of these mostly high-energy injuries is the significant instability of all columns. Signs of segmental torsion like fractures of the processus transversus, vertebral bows, or facet joints as well as alterations of the processi spinosi in the a.p. view can be found. The rare rotation-shear injuries (C3) occur through high-velocity trauma, in general an axle-dislocation "ad latum" is pathognomonic. Severe neurological symptoms are frequently combined with these types of injuries.

Type C: Anterior and posterior element injury with rotation
- C1: Type A injuries with rotation
- C2: Type B injuries with rotation
- C3: Rotational-shear injuries

Vaccaro et al. developed a new subaxial cervical spine classification system with the Spine Trauma Study Group [33]. Their subaxial injury classification (SLIC) severity scale abandons traditional characteristics of mechanism of injury and anatomy in favor of injury morphology and neurologic status. It is based on three components of injury:

1. Morphology
2. Discoligamentous complex integrity
3. Neurological status

All three are independent determinants of prognosis and management. A numerical value is generated from different categories, specific to the descriptive identifier. Injury patterns that result in the worst outcome or require surgical treatment are weighted to receive higher point values. The higher the number of points assigned to a particular category, the more severe the injury may be and the more oblique a surgical procedure is indicated.

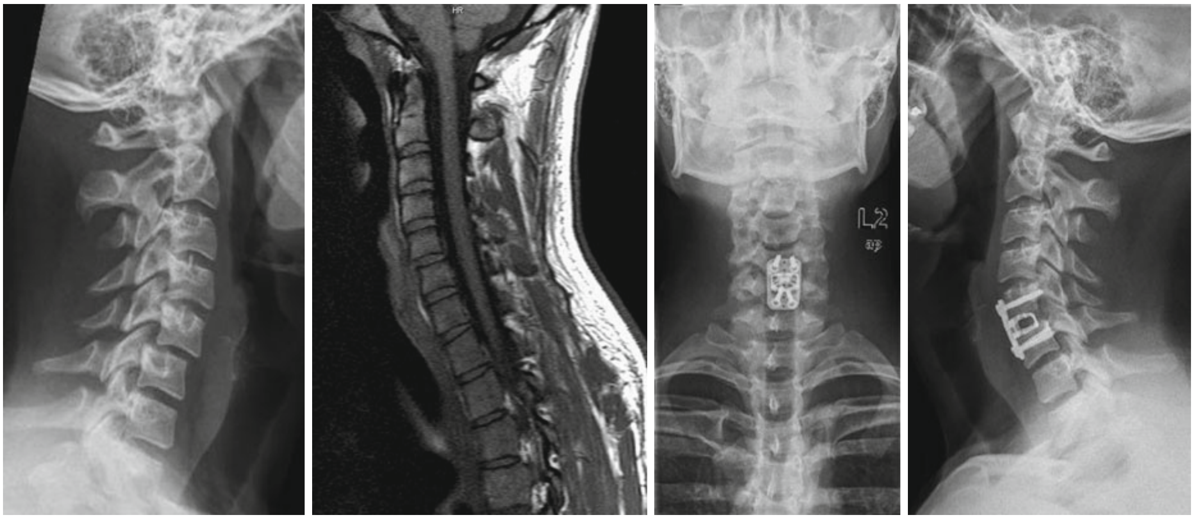

Fig. 15.20 (**a–d**) Twenty-three-year-old patient with discoligamentic instability of C5/6 after landing on the head following a dive into shallow water, treated from anterior with discectomy, cage, and plate; no neurology

Diagnosis

The early identification of a spinal trauma has absolute priority, therefore, the first examination has to be conducted by the emergency physician. In case of an unconscious patient, the mechanism of the accident can provide important information. Cervical spine injuries of type A often occur after a jump into shallow water, and also in cases of cranial impinging forces. Type-B injuries often appear in connection with car accidents under high kinetic energy. Combined with cervical trauma, second- or third-degree craniocerebral injuries are often seen in 10 % of patients, and in cases of polytrauma, the rate is up to 20 %.

To verify injuries of the lower cervical spine, conventional X-rays in a.p. and lateral view should be performed. In addition, functional images can be taken to measure instabilities in the segments in flexion or extension. In case of lesions in the cervicothoracic transition zone, the swimmer's view can provide important information. The gold standard is, as with the upper cervical spine, the CT, whereas MRI can detect ligamentous injuries and lesions of the discs, myelon nerve roots, or muscles. It also has the advantage of being a radiation-free procedure. Additional information may be gained through angio-CT or MRI.

Therapy

The lower cervical spine can be reached via the anterior or posterior approach. The anterior approach is the standard procedure in the therapy of all traumatic injuries of the lower cervical spine, whereas in case of injuries of the cervicothoracic transition zone, posterior stabilization is chosen instead. The demonstration of the cervicothoracic region can be accomplished through a left-sided approach to avoid an injury of the right N. laryngeus superior, which runs more cranial. In case of long line stabilizations, the incision should be made at the anterior margin of the M. sternocleidomastoideus. Indications for a posterior approach of the lower cervical spine are irreducible mono- or bilateral luxations of the facets (type B1.1) and fractures with a rotational luxation (type C2.1).

Since the late 1970s, anterior plate fixation as a routine procedure and posterior fixation in cervical spine injuries are only used in cases where anterior stabilization cannot be performed. This depends from the type of lesion.

Laminectomies are seldom indicated in the cervical spine in the context of spinal cord trauma. Most - cord compression is caused by instability or dislocation of bone fragments or parts of the disc, which come mostly anteriorly. Therefore, the compression of the spinal cord by bony fragments is mainly treated by the anterior approach, and stabilization is accomplished by plates and cages in case of discoligamentous injuries [1] (Fig. 15.20).

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Spine

16

Markus Schultheiss, Daniel Gulkin,
and Florian Gebhard

16.1 Fractures of the Thoracic and Lumbar Spine

16.1.1 Definition

- Increased risk of neurological deficits between Th4 and Th9 resulting from the relative stenosis of the spinal canal (physiologic) and the reduced perfusion of the spinal cord.

16.1.2 Epidemiology

In most cases, the thoracolumbar junction is affected (approximately 50 % include Th12 or L1).

16.1.3 Historical Background

The first classification was introduced by Böhler in 1929. It contained five subtypes.

16.1.4 Classification/Grading

To describe vertebral fractures in vertebrae with similar morphology, the classification according to Magerl et al. [2] can be used.

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This classification acknowledges the forces that occur during the spinal injury (compression, distraction, and translation/rotation). Thus, the following classification system:
Type A injuries: caused by compressive forces
Type B injuries: caused by distractional forces
Type C injuries: caused by rotational forces

16.1.4.1 Classification According to Magerl

- Standardized classification for vertebrae C3–L5
- Divided into main (A–C) and subcategories (1–3)
- Instability and neurological complication rate increase in main categories from A to C and in subcategories from 1 to 3

Classification of the spinal fractures according to Magerl:

Type-A Injuries

Compression (usually at the thoracolumbar junction):

- A 1: Compression fractures show little deformity and are usually stable.
  - A 1.1: End-plate impaction
  - A 1.2: Wedge impaction
  - A 1.3: Corpus collapse
- A 2: Sagittal and dislocated split fractures along with pincer fractures are unstable.
  - A 2.1: Sagittal split
  - A 2.2: Coronal split
  - A 2.3: Pincer
- A 3: Burst fractures are unstable.
  - A 3.1: Incomplete burst
  - A 3.2: Burst split
  - A 3.3: Complete burst

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Type-B Injuries

Flexion/distraction fractures (most commonly seen at the cervicothoracic junction):

- B 1: Flexion/distraction injuries are unstable because of the rupture of the dorsal ligament structures.
  - B 1.1: Accompanying transverse disruption of the disc
  - B 1.2: Accompanying ventral damage through a fracture of the vertebral body (Type A)
- B 2: Transosseous Flexion/distraction injuries are unstable.
  - B 2.1: Ventral damage in the form of transverse bicolumn rupture of the vertebral body
  - B 2.2: Ventral damage in the form of flexion-spondylolysis through disc rupture
  - B 2.3: Ventral damage in the form of an accompanying fracture Type A
- B 3: Hyperextension/dislocation injuries are primarily ruptures of the ventral column and present highly unstable.
  - B 3.1: Hyperextension/subluxation
  - B 3.2: Hyperextension/spondylolysis
  - B 3.3: Complete posterior luxation

Type-C Injuries

Rotational injuries (most common at the cervical spine):

- C 1: Rotation + compression
  - C 1.1: Accompanied by Type A1 fracture (wedge)
  - C 1.2: Accompanied by Type A2 fracture (split)
  - C 1.3: Accompanied by Type A3 fracture (burst)
- C 2: Rotation + flexion/distraction
  - C 2.1 + B1
  - C 2.2 + B2
  - C 2.3 + B3 (shear)
- C 3: Rotational/shear fractures: “Slice” fractures according to Holdsworth
  - C 3.1 Shear slice fracture
  - C 3.2 Shear oblique fracture

16.1.5 Etiology/Pathogenesis

- The type of accident and injury pattern can point to the actual suffered injuries of the spine and spinal cord:
  - Thoracic spine type-A/C injury: powerful axial impact (e.g., motorcycle accidents, suicidal leaps, etc.)
  - Lumbar spine type-A/C injury: fall and impact with pelvis or lower extremities leading (e.g., fall from a horse, paragliding accidents)

16.1.6 Clinical Symptoms

- The rescue of an injured patient with possible spine involvement has to be handled delicately until an injury to the spine can be ruled out after imaging:
  - Immobilize patient using a full-body vacuum mattress and/or stiff-neck collar
- Pain location points to the site of the injury if the patient can be addressed.
- The neurological state must be evaluated completely by the emergency doctor or medic and later on in the emergency room by the trauma surgeon.

Important aspects of physical and neurological exams are as follows:

Pain localization
External signs of injury (hematoma, deformities)
Relieving posture
Motor or sensory deficit
Reflexes
Medullary or radicular symptoms
Paralysis, complete or incomplete spinal cord injury

- The location of pain can point out the damage suffered by the spine.

  The following symptoms may occur:
- Restricted movement
- Pain (local, induced by movement, radiating)
- Medullary symptoms showing complete or incomplete paraplegia
- Radicular symptoms
- Increased neck circumference caused by prevertebral bleeding
- Spinal shock
- Specific symptoms of accompanying injuries
- In patients with spine injuries, the complete neurological state needs to be assessed by the emergency physician and the treating physician in the hospital:
  - Sensory perception includes touch/pain and temperature sensations (nociceptors) as well as spatial information such as vibration/position of the limbs (proprioceptors).
  - Evaluation of the reflex state consists of examination of physiologic and pathologic body reflexes.
- In cases of combined injuries to the spine and cranium, the reflex state can be used to distinguish between central and medullary lesions:
  - The absence of muscle tendon reflexes combined with flaccid paralysis points out a medullary lesion.
  - Intact muscle tendon reflexes combined with flaccid paralysis suggest a central (intracranial) lesion.

Table 16.1 Evaluation of the neurological state in patients with spine injuries

	Key muscles	Key sensory points	Reflexes
C4	Shoulder elevation (M. deltoideus)	Shoulder	C5/6 Biceps tendon reflex
C5	Elbow flexion (M. biceps, M. brachioradialis)	Lateral upper arm	C5/6 Brachioradial tendon reflex
C6	Wrist extension (M. extensor carpi radialis)	Thumb	
C7	Elbow extension (M. triceps)	Middle finger	C7/8 Triceps tendon reflex
C8	Finger flexion (M. flexor digitorum profundus)	Small finger	
Th1	Small finger abduction (M. abductus digitus minimus)	Medial elbow	
Th5		Mamillae	
Th10		Umbilicus	
L2	Hip flexion (M. iliopsoas)	Medial upper thigh	L1/2 Cremasteric reflex
L3	Knee extension (M. quadriceps)	Medial thigh and knee	L3/4 Knee tendon reflex
L4	Ankle dorsiflexion (M. tibialis anterior)	Medial lower leg	
L5	Great toe extension (M. extensor hallucis longus)	Great toe	
S1	Ankle plantarflexion (M. gastrocnemius)	Small toe and lateral foot	S1/2 Achilles tendon reflex
S3-5		Saddle anesthesia	S3/4 Bulbocavernosus reflex
S4	Anal sphincter tension	Saddle anesthesia	S3/4 Anal reflex

Table 16.2 Muscle strength grading

0	Total paralysis
1°	Palpable or visible contraction
2°	Full range of motion with gravity eliminated
3°	Full range of motion against gravity
4°	Full range of motion with decreased strength
5°	Normal strength

- Unilateral weakened reflexes point out a radicular lesion, whereas segmental (bilateral) weakness indicates a recent medullary injury (Table 16.1).

- Motor strength is quantified as described in Table 16.2.
- Cord injury is assessed according to Frankel (Table 16.3).

Alternatively, the ASIA (American Spinal Injury Association) classification can be used to assess the deficit.

ASIA classification of motor dysfunction:

0 = Total paralysis
1 = Palpable or visible contraction
2 = Full range of motion with gravity eliminated
3 = Full range of motion against gravity
4 = Full range of motion with decreased strength
5 = Normal strength
NT = Not testable

ASIA classification of sensory deficit, based on each dermatome:

0 = Absent
1 = Impaired
2 = Normal
NT = Not testable

Table 16.3 Classification of cord injury according to [1]

Type A	Complete	No motor or sensory function is preserved below the neurological level
Type B	Incomplete	Sensory but not motor function is preserved below the neurological level
Type C	Incomplete	Motor function is preserved below the neurological level and more than half of key muscles have a muscle grade < 3
Type D	Incomplete	Motor function is preserved below the neurological level and at least half of key muscles have a muscle grade of 3 or more
Type E	Normal	Motor and sensory functions are normal

- Spinal shock is an acute, transient state of paraplegia or tetraplegia, flaccid muscle tone, absent reflexes, bladder overflow incontinence, paralytic ileus, etc., even in the absence of osseous injuries.
- After an initial spinal shock, complete cord injuries turn into spastic plegia and hyperreflexia showing extensor/flexor reflex synergies and involuntary bladder incontinence.
- Spinal cord lesions at the C-spine level are defined as tetraplegia:
  - Ultrahigh tetraplegia are lesions above the C4-level, high tetraplegia between C4 and C6. The loss of thoracic respiration combined with a reduced vital capacity and decreased clearance of pulmonary secretion is what all tetraplegiae have in common.

– Paraplegia describes lesions of the spinal cord on the thoracic level with sustained functionality of arms and hands. High paraplegia is a lesion below C8 but above Th4 leaving the latissimus dorsi and trapezius muscles functional. Low paraplegia shows lesions below Th4. Tetraplegia and paraplegia both show complete loss of bladder and rectal control, the loss of sensory perception (pain/temperature, touch/spatial information) and loss of vegetative regulation (regulation of blood vessels, body temperature and functional impairment of organs).

16.1.7 Diagnostics

- X-ray: a.p. and lateral
- CT scan: image reconstruction allows for a detailed evaluation of fractured parts
- MRI: to identify existing injuries to the spinal cord, spinal nerves, and ligaments

16.1.8 Treatment

The decision of whether to do a stabilizing/fusion procedure or spinal cord decompression is influenced by accompanying injuries and neurological symptoms.

The exact timing of an operative intervention as part of the treatment concept is of great importance.

- *Immediate intervention*:
  - Complete injury of the spinal cord (Frankel A)
  - Incomplete but progressing injury (Frankel C)
  - Paralysis after an interval without symptoms (Frankel B)
  - Open spinal cord injury
- *Urgent indication for operative treatment within 6 h*:
  - Radicular neurological symptoms
  - Cauda equina symptoms
  - High-grade instability (Type B and C)
  - Significant stenosis of the spinal canal (without neurological symptoms)
- *Elective indication for operative treatment within days*:
  - Closed nonreducible injuries
  - Posttraumatic vertebral deformities (Type A)
  - Traumatic disc injuries

16.1.8.1 Thoracic Spine Type-A Injuries

Nonoperative Treatment

- End plate impaction (A 1.1)
- Corpus collapse (A 1.3)
- Nondislocated sagittal split fractures (A 2.1)

Operative Treatment

- Dorsal Instrumentation (fusion):
  - Incomplete burst fractures (Type A 3.1) showing wedging of >10° and <20°

Procedures

- Dorsal or ventral instrumentation:
  - After initial dorsal fusion of incomplete burst fractures (A 3.1) and burst split fractures (A 3.2), an additional ventral approach after CT-scan evaluation might be indicated. The decision as to whether to add ventral stabilization is influenced by the axial weight-bearing capacity of the affected vertebra, the remaining compression of the canal, the defect of the intervertebral disc's pocket, and the degree of posttraumatic wedging (>20°).
  - A combination of both procedures is usually indicated for complete burst fractures (A 3.3).

16.1.8.2 Thoracic Spine Type-B Injuries

For Type-B injuries, the preferred procedure is the dorsal transpedicular fusion.

16.1.8.3 Thoracic Spine Type-C Injuries

- All Type-C injuries are indications for fusion/stabilization. Dorsal instrumentation as the primary procedure is preferred.
- Accompanying intrathoracic injuries also affect the choice of therapy in rotational injuries at the thoracic spine.

Operative Management

- Dorsal fusion is the standard procedure
- Dorsal fusion is indicated for incomplete burst fractures Type A 3.1 with additional wedging of >10° as well as for all Type B and C injuries (dorsal and/or ventral approach; single-step or two-step)
- Reduction and correction of gibbus deformity are difficult to accomplish in thoracic spine intervention because of the stabilizing character of the thorax.
- A ventral approach is indicated in vertebra deformities (A 3.2 und A 3.3) with additional

wedging of >20° and ventral compression of the spinal cord.

Specific Operative Procedures

- Dorsal approach:
  - Patient in prone position. Incision after fracture is located using fluoroscopy, transection of the aponeurosis, subperiosteal dissection of the paraspinal muscles, and exposure of the intervertebral joints.
  - Costotransversectomy with partial resection and replacement of vertebral body if needed.
- Ventral approach:
  - Depending on location:
  - Th1–Th3: open anteromedial approach after sternotomy
  - Th4–Th11: open transthoracic approach with patient in lateral position (left or right, depending on location of the vessels)
- Minimally invasive technique:
  - Thoracoscopic approach using a bilumen tube with patient in lateral position (left or right, depending on the location of the vessels indentified through a CT scan) for Th5–L2.
  - Retroperitoneal approach with patient in right lateral position for L1–L5.

16.1.8.4 Operative Stabilization Procedures with Dorsal Approach

- Dorsal transpedicular screw-and-rod system.
- Computer-assisted intraoperative navigation when needed.
- Hardware removal after approximately 9 months in accordance with CT scan.

16.1.8.5 Operative Stabilization Procedures with Ventral Approach

- Mono- or bisegmental fusion using autograft bone or alternative artificial vertebral replacement
- Locking plate system
- Endoscopic technique (Figs. 16.1 and 16.2)
- No need for hardware removal

Complications

Nonunions, hardware failure or loosening, loss of correction, infection, neurological complications, intrathoracic or retroperitoneal injuries, paralytic ileus, pneumonia

16.2 Thoracic and Lumbar Vertebral Fractures Caused by Osteoporosis

16.2.1 Definition

- There are multiple causes, ranging from "silent" fractures without any external force causing the injury (osteoporosis-induced height loss) to acute traumatic events (trauma-induced osteoporotic fractures).

16.2.2 Epidemiology

In the United States, there are approximately 700,000 osteoporotic compression fractures of the vertebral body. In Europe, the estimated number for these injuries is 1.4 million cases.

16.2.3 Historical Background

Treatment of osteoporotic impaction fractures has changed significantly since the invention of minimally invasive PMMA augmentation of the vertebral body. Although the first vertebroplasty was performed in France in 1984 by Deramond and Galibert, it was not until 1998 that the first balloon kyphoplasty was performed in the United States.

16.2.4 Classification/Grading

Classification

- Primary (95 %):
  - Postmenopausal (Type 1).
  - Senile osteoporosis (Type 2).
- Secondary (5 %):
  - Immobilization
  - Steroid therapy
  - Metabolic diseases

16.2.5 Etiology/Pathogenesis

- The anterior column is affected in most cases of osteoporotic fractures because the disentanglement of the cancellous bone mechanically weakens the vertebra (subtle process).

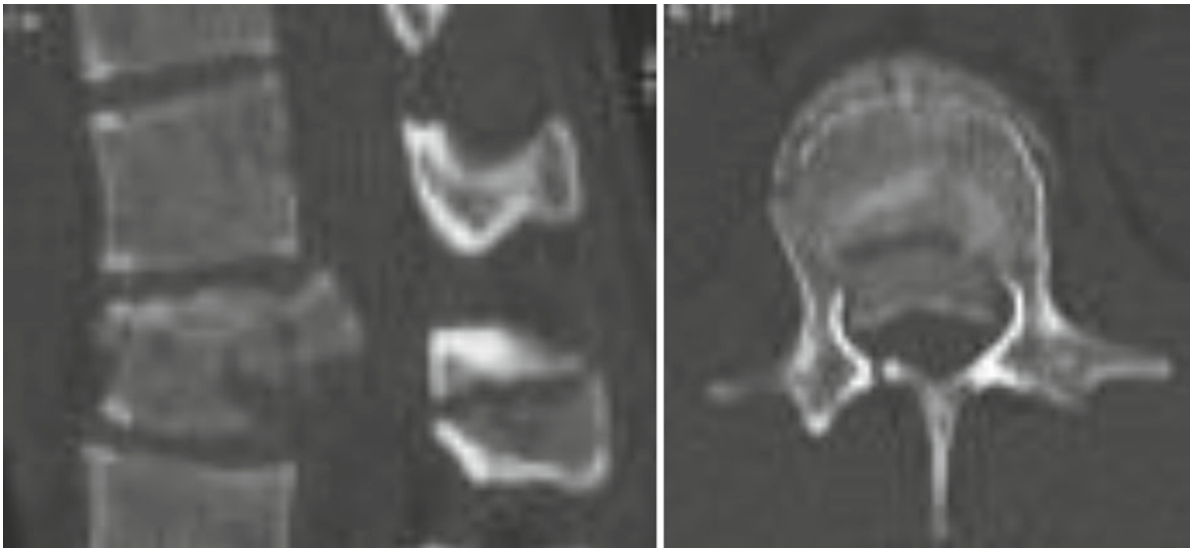

Fig. 16.1 Type C 1.3 fracture of L 1

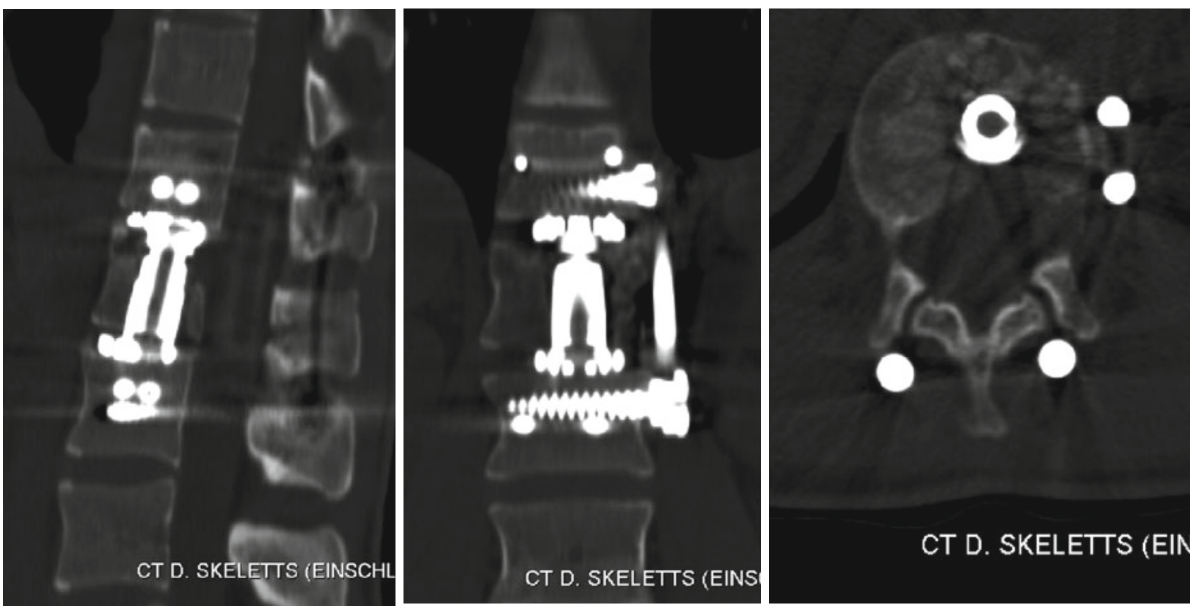

Fig. 16.2 Dorsoventral, bisegmental stabilization T 12/L2 (endoscopic anterior decompression and replacement of vertebral body and plate fixation)

- The risk of sustaining a spinal injury increases with worsening osteoporosis.
- Risk factors for primary osteoporosis are
  – Estrogen deficiency
  – Early menopause (age <45 years)
  – Familial disposition with hip fractures on the maternal side
  – Low body mass index (<19 kg/m^2)
  – Earlier fractures, particularly located at the hip, spine, or wrist
  – Loss of body height or formation of thoracic kyphosis (hunchback)
  – Female gender
  – Asian or Caucasian race

– Lack of exercise
– Smoking
– Regular or extensive alcohol consumption

16.2.6 Clinical Symptoms

- Gradually increasing pain or decreasing activity or even immobility
- Neurological deficit in some cases

16.2.7 Differentials

Degenerative diseases of the spine

16.2.8 Diagnostics

- X-ray: a.p. and lateral
- CT-scan: image reconstruction allows for a detailed evaluation of fractured parts
- MRI enables evaluation of neural structures and tissue

16.2.9 Treatment

16.2.9.1 Nonoperative Treatment

- Drug therapy of osteoporosis is mandatory.

16.2.9.2 Operative Treatment

- Operative intervention of osteoporotic compression fractures is indicated if:
  – Pain is not controllable
  – Mobility is lost

Procedures

- Minimally invasive:

Kyphoplasty: after percutaneous, bilateral transpedicular balloon dilation, the defect is filled with highly viscous bone cement (PMMA) through a tube system.

- Operative intervention of trauma-induced fractures combined with osteoporosis:
  – Dependent upon whether or not there is a neurological deficit
  – Open dorsal laminectomy and spinal fusion with screws and rods when needed

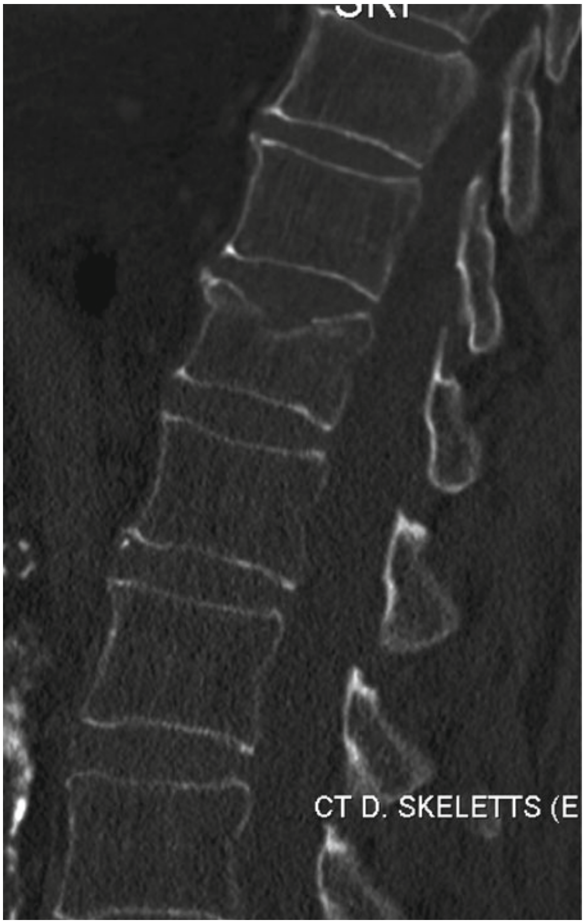

Fig. 16.3 Osteoporotic fracture T 12

  – Possibility of using cannulated slit pedicle screws that allow cement augmentation and therefore present higher stability in an osteoporotic bone
  – Combination of kyphoplasty and dorsal spinal fusion

Complications

PMMA leakage, refractures, hardware failure or loosening, loss of correction, infection, neurological complications (Figs. 16.3 and 16.4)

16.3 Thoracic and Lumbar Vertebral Fractures due to Metastasis

16.3.1 Definition

- Osteolytic or osteoblastic metastases of a primary tumor developing at the spine

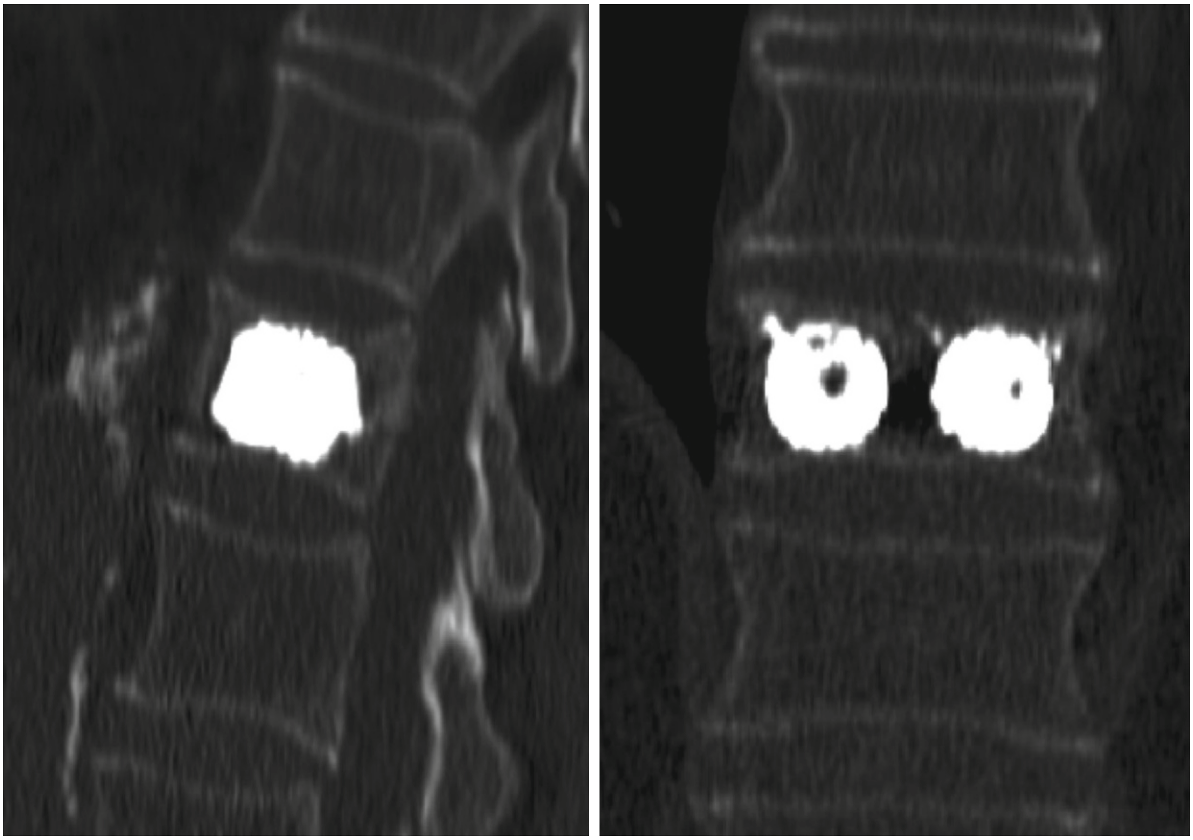

Fig. 16.4 Reduction and stabilization with vertebral body stents T12

16.3.2 Epidemiology

- Sixty percent of all skeletal metastases affect the spine (ratio cervical:thoracic:lumbar 4:6:1).

16.3.3 Historical Background

With gradually improving therapy of primary tumors, the incidence of skeletal metastases will increase as a result of the prolonged survival rate.

16.3.4 Classification/Grading

- To assess whether or not to operatively stabilize an instability of the spine, the Taneichi score [4] should be used in combination with a CT scan:
  - At the thoracic spine, at least 50 % of the vertebral body needs to be affected, or 25–30 % in combination with at least one affected facet joint.
  - At the lumbar spine, at least 50 % of the vertebral body needs to be affected, or 35–40 % in combination with at least one affected pedicle.

16.3.5 Etiology/Pathogenesis

- Malignant tumors often associated with osseous metastases are:Breast cancer
  Prostate cancer
  Bronchial carcinoma
  Thyroid cancer
  Renal cancer
- Eighty-five percent of all spinal metastases affect the vertebral body.

16.3.6 Clinical Symptoms

- Pain
- Decreased mobility
- Neurological deficits

Table 16.4 Karnofsky Index

Able to carry on normal activity and to work; no special care needed	1. Normally no complaints; no evidence of disease	100 %
	2. Able to carry on normal activity; minor signs or symptoms of disease	90 %
	3. Normal activity with effort; some signs or symptoms of disease	80 %
Unable to work; able to live at home and care for most personal needs; varying amount of assistance needed	4. Cares for oneself; unable to carry on normal activity or to do active work	70 %
	5. Requires occasional assistance, but is able to care for most of one's personal needs	60 %
	6. Requires considerable assistance and frequent medical care	50 %
Unable to care for oneself; requires equivalent of institutional or hospital care; disease may be progressing rapidly	7. Disabled; requires special care and assistance	40 %
	8. Severely disabled; hospital admission is indicated although death not imminent	30 %
	9. Very sick; hospital admission necessary; active supportive treatment necessary	20 %
	10. Moribund; fatal processes progressing rapidly	10 %
	11. Dead	0 %

16.3.7 Differentials

Degenerative diseases of the spine

16.3.8 Diagnostics

Imaging

- X-ray: a.p. and lateral views
- CT scan: to diagnose osseous lesions
- MRI: to diagnose osseous lesions or injuries to the ligaments
- Three-phase bone scintigraphy for staging purposes if needed
- PET-CT scan for staging purposes if needed

16.3.9 Treatment

- The treatment of metastases to the spine should consist of an interdisciplinary therapy concept.
- Evaluation of the total time of survival and the associated possibilities of operative intervention can be accomplished using the Karnofsky index in combination with the Tokuhashi score (Tables 16.4 and 16.5).

16.3.10 Treatment

In patients with osseous metastases, painless mobilization and an increase in quality of life can be achieved in most cases through an interdisciplinary consensus. The individual therapy regimen should always be developed in an interdisciplinary manner.

Table 16.5 Tokuhashi Score [4]

		Scoring points
General condition (Karnofsky index)	Poor (10–40 %)	0
	Moderate (50–70 %)	1
	Good (80–100 %)	2
Number of extraspinal bone metastases	>3	0
	1–2	1
	1	2
Number of metastases in the vertebral bodies	>3	0
	1–2	1
	1	2
Metastases to the major internal organs	Removable	0
	Not removable	1
	No metastases	2
Primary site of the cancer	Lungs, stomach, esophagus, pancreas, bladder, osteosarcoma	0
	Liver, gall bladder	1
	Other	2
	Kidney, uterus	3
	Rectum	4
	Thyroid, breast, prostate, carcinoid	5
Spinal cord palsy	Complete (Frankel A, B)	0
	Incomplete (Frankel C, D)	1
	None (Frankel E)	2
Estimated prognosis:	Score equal to or < 8: < 6 months	
	Score 9–11: 6 months to 1 year	
	Score > 12: >1 year	
Therapeutic options:		
0–8	Nonoperative action	
9–11	Palliative, operative procedures: laminectomy + stabilization, R2 resection when indicated	
12–15	R0/R1 resection and stabilization/vertebral body replacement	

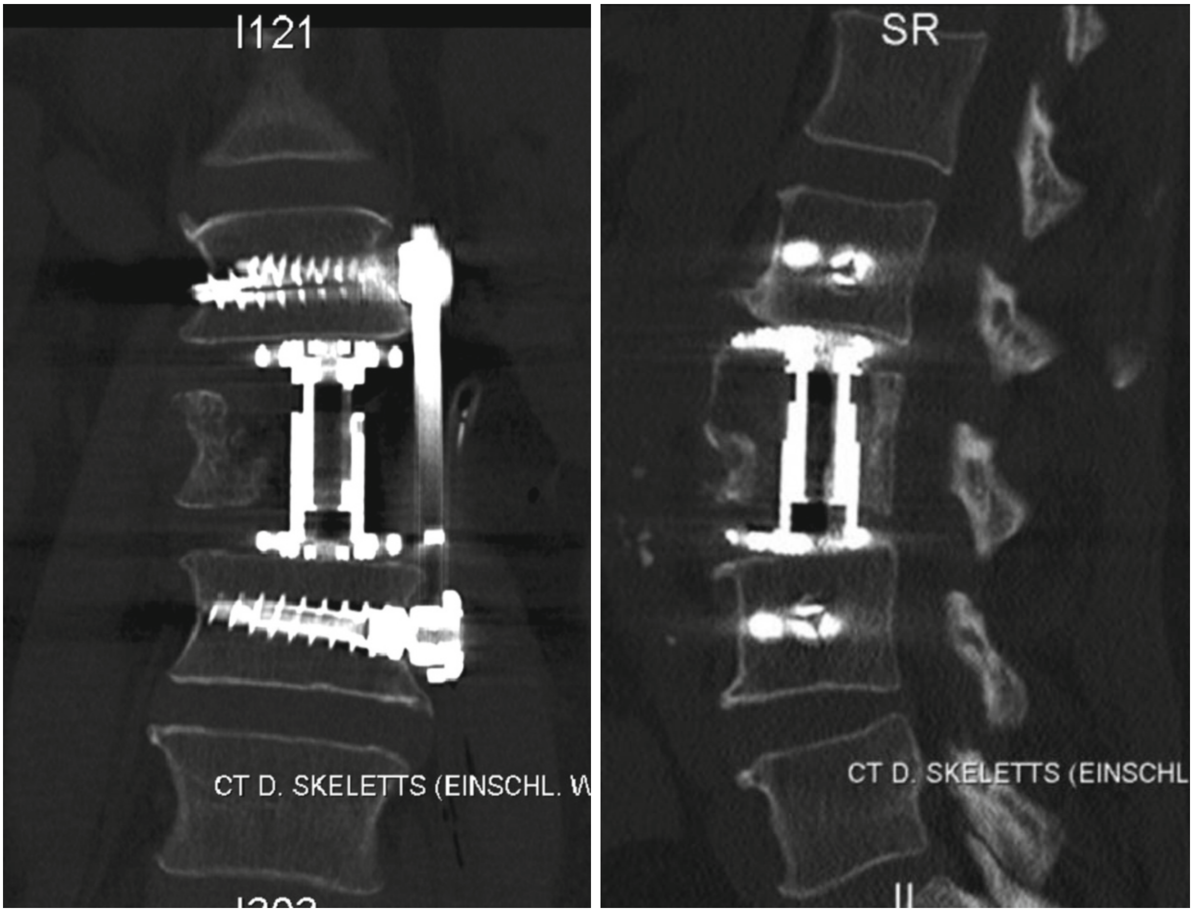

Fig. 16.5 Replacement of a thyroid cancer-affected L 3 vertebral body and plate fixation

16.3.10.1 Nonoperative Treatment

Treatment with a corset and radiation if indicated

16.3.10.2 Operative Treatment

- Preventive or secondary stabilizing procedures in case of fractures should always be adapted to the individual situation. This situation is highly influenced by the type of the tumor, the progressive course of the disease and the conducted therapy as well as the stage of the disease.

Procedures

- In most cases, dorsal fusion and laminectomy
- Minimally invasive dorsal fusion or kyphoplasty in cases of mere instability without spinal compression
- Vertebral body replacement and fusion through a ventral approach in cases of solitary metastases; additional postoperative radiation if indicated

Complications

PMMA leakage, refractures, hardware failure , loss of correction, infection, neurological complications, tumor progress

16.3.10.3 Additional Treatment Options

- Adjuvant hormone therapy or chemotherapy
- Postoperative radiation if indicated
- Analgesics according to WHO pain ladder, radiation for analgesic purposes
- Bisphosphonate therapy (Fig. 16.5)

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Pelvic and Acetabular Fractures

17

Reiner Wirbel and Tim Pohlemann

17.1 Biomechanics

The innominate bone is structured as a ring formation corresponding to its main function to transfer the body load from the spine to the lower extremities. The two iliac bones and the dorsally trapped sacrum build the osseous frame, connected by the sacroiliac joint and the symphysis. By inclination of the pelvic in the horizontal plane (60°) and by the S-shaped erection of the spine in the lateral plane, the balance point of the body positioned vertically lies in front of the spine. Thereby, a Y-shaped load transmission from the pelvis to the lower extremities occurs. By the interaction of musculature, ligamentous structures, and bony components, the load capacity of the pelvis is guaranteed. Biomechanically, the pelvis can be divided into an anterior and posterior ring segment, whereby the posterior sacroiliac ligaments are of main importance for the stability of the pelvic ring.

Because the center of rotation of the pelvis is located dorsally of the centers of the femoral heads, the pelvis is affected by rotational forces in a vertical position of the body. The rotational forces are balanced by intact symphysis and by posterior ligamentous structures. Thus, an intermittent changing of compression and of traction results when moving.

Fractures of the posterior pelvic ring yield a destabilization of the ring system, producing an "unstable" pelvic ring, whereas no relevant mechanical impairment of the ring system is seen in fractures of anterior pelvic ring and the pelvic ring remains "stable."

In cases of unstable pelvic ring injuries, the spatial arrangement of the pelvis is changed and the physiological distribution of forces is interrupted. Instabilities reduce the tension of the pelvic ring and, therefore, the kinematics.

This balanced system can remain deranged after operative treatment of pelvic ring injuries by ligamentous lesions, resulting in only moderate clinical outcome despite anatomically osseous reconstruction of the pelvic ring.

17.2 Epidemiology of Pelvic Injuries

Pelvic fractures are rare injuries, with a frequency of 20–37 per 100,000. The frequency of all fractures lies between 3 and 8 %. There are two groups in which increased frequencies are seen. The first peak is seen in the age group of 20–30 years, mostly caused by polytrauma, such as car accidents and falls from a great height. The second is seen in the seventh decade, mostly in women, where low-energy falls result in pubic and/or ischiadic bone fractures.

In polytrauma, pelvic ring injuries are presented in about 20–25 % of cases with a lethality of 40 %. The studies of the AO International and the German

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Table 17.1 Epidemiology of pelvic ring injuries (study group pelvis of AO) ($n = 2,551$)

Fracture type	Internal fixation performed (%)	
Type A	55	3.9
Type B	25	37.3
Type C	20	54.3
Complex trauma	12	57.5
+ Acetabular fracture	15	
Concomitant injuries		
Head	40	
Thorax	36	
Abdomen	25	
Spine	15	
Peripheral skeleton	69	
Urogenital	5 (50 in complex trauma)	

Table 17.2 Epidemiology of isolated acetabular fracture (study group pelvis of AO, $n = 704$; and according to Letournel and Judet, $n = 940$)

	Frequency (%)	
Fracture type	Letournel & Judet (%)	Study group pelvis (AO) (%)
Posterior wall	24	14
Posterior column	3	11
Anterior wall	2	2
Anterior column	4	13
Transverse	7	17
Posterior column + posterior wall	3	5
Transverse + posterior wall	20	7
T-type	7	8
Anterior column + post. hemitransverse	7	3
Both columns	23	20

Multicenter Study Group (Pelvis) of the German Trauma Society include 3,260 pelvic ring and acetabular fractures. Tables 17.1 and 17.2 give a survey of the distribution of fracture types, of the frequency of operative stabilization, and of concomitant injuries.

The rate of neurological concomitant lesions was 11 % in complex trauma.

In fractures of type C, 50–70 % of the patients were polytraumatized.

In the above-mentioned study, isolated acetabular fractures are seen in 21 % of all pelvic injuries. In a large series by Judet and Letournel (940 patients), the most frequent fracture types (for classification, see below) were the posterior wall fracture, the transverse and the posterior wall fracture, and the two columns fracture, each with a frequency of 20–25 % (Table 17.2). In 15 % of the acetabular fractures, concomitant injuries of the pelvic ring were found, and in 45 % there were additional fractures of the peripheral skeletal system. According to Judet and Letournel, neurological damages were seen in 12 %; in two-thirds of the cases there were fractures of the posterior column or of the posterior wall.

Pediatric pelvic ring and acetabular injuries are extremely rare. Because of the increased elasticity and therefore associated high restoring forces of the pediatric pelvic ring, only radiographically minimally displaced fractures can be found, despite high-energy impact, whereby those fractures are often undervalued. The frequency of complex pelvic ring injuries in children is about 20 %, twice as much as in adolescents. Acetabular fractures in children are also extremely rare; the percentage of all pediatric fractures accounts for about 0.01 %. Mostly, disruptions of the Y-shaped epiphyseal plate are found.

17.3 Classification of Injuries

Generally, injuries of the pelvis can be divided into pelvic ring injuries and acetabular fractures.

The *pelvic ring injuries* can be classified as isolated osseous or ligamentous injuries, with or without instability of the pelvic ring, and as *complex pelvic trauma*.

Patients presenting with a combination of pelvic fracture and concomitant soft tissue injuries have a fourfold higher lethality compared with those suffering from an isolated, "uncomplicated" pelvic fracture. Therefore, the term *complex pelvic injury* has been established. Complex pelvic injuries are characterized by soft tissue injuries, including extensive subcutaneous décollements (Morel-Lavallée syndrome), urogenital injuries, and anorectal impalements. The stability of the pelvic girdle is mainly dependent upon the integrity of the posterior sacroiliac ring segment, consisting of the posterior parts of the iliac bones, the sacrum, and their ligamentous connections. The extent and localization of the interruption of the pelvic girdle determine the classification, whereas smooth transitions between the different directions of instability are possible.

Acetabular fractures are classified according to Letournel, who established a consideration of an "anterior" and "posterior" column into the morphological analysis of acetabular fractures. The classification of Letournel is the basis of all further analyses and classifications. Based on this classification, there are five elementary fractures, where it is about column, transverse, and wall fractures, and five combined fracture types.

17.4 Pelvic Ring Injuries

17.4.1 Injury Mechanism

Pelvic ring injuries are mostly the result of high-energy trauma with direct or, transferred via the femur, indirect energy impact. In about 52 % of cases pelvic ring injuries are caused by car accidents, in 37 % by falls from a great height, and in 11 % by other injuries. Severe open pelvic trauma (crush injury) is mostly caused by a run over by a vehicle.

In principle, three vectors of energy impact to the pelvic girdle can be defined (Fig.17.1):

The *anterior-posterior compression* with an anterior or posterior impact to the pelvic girdle results in an external rotation movement of the hemipelvis presenting the so-called "open-book" mechanism. In this type of injury, the posterior ligamentous structures are partially intact.

The *lateral compression* is the most common energy impact to the pelvic girdle (75 %). Posterior-lateral impact will result in a rupture of the symphysis or in pubic rim fracture, whereas anterior-lateral impact will cause an internal rotation movement of the hemipelvis with partial disruption of the posterior ligamentous structures.

The *vertical shear* mechanism consists of a vertical energy impact to the posteriorly stabilizing structures of the pelvic ring segment. Translational movements will result in a complete disruption of the pelvic girdle posteriorly and anteriorly. The posterior injuries can be presented as disruptions of ligamentous structures or as osseous lesions of the sacrum or the iliac bone. Because "directions" in the various positions of the pelvis often cannot be determined sufficiently, the vertical shear mechanism is increasingly constituted as a *translation injury* because the direction of movements are irrelevant for the complete disruption of the sacroiliac structures.

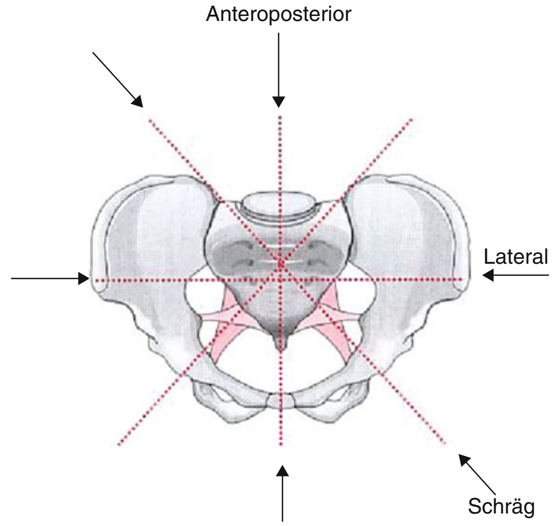

Fig. 17.1 Vectors of energy impact to the pelvic ring

17.4.2 Classification

The classification is based on the direction of energy impact to the pelvic girdle. Thereby, the fracture course and the stability of the integrity of the pelvic girdle are determined. The A-B-C system according to Müller, Isler, and Ganz, which is assumed by the AO/OTA, has been established for the classification of pelvic ring injuries. The graduation proposed by Pennal considering the pure injury mechanism is combined with the classification according to Tile, who respects the degree of instability of the pelvic girdle.

In daily practice, the pelvic ring injury is divided into a stable and unstable type. Additionally, the direction of the instability is indicated, that is, in the anterior pelvic ring segment, transpubic and transsymphyseal instability, and in the posterior ring segment, transiliac, transsacroiliac, transsacral, and transacetabular instability. The AO/Ota classification is the first system that allows a complete alphanumeric graduation of all injuries by separated reflection of the anterior, posterior, right, and left pelvic ring segment.

17.4.2.1 Type A Injuries

Pelvic rim or pelvic ring injuries without loss of pelvic stability (Fig. 17.2).

Type A fractures are stable fractures. Examples are avulsion fractures, iliac wing fractures, pubis or ischial

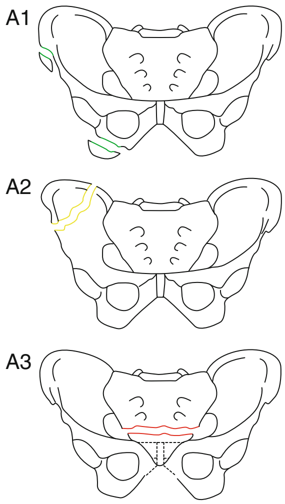

Fig. 17.2 Classification of type-A pelvic ring fractures

rim fractures, as well as transverse sacral fractures below the sacroiliac joint.

Type A 1: Iliac wing fracture

Type A 2: Anterior pelvic ring fracture with minimal lesion of the posterior ring segment not compromising the stability of the pelvic ring

Type A 3: Transverse sacral or coccygeal fracture (below the sacroiliac joint)

17.4.2.2 Type B Injuries

Type B injuries are characterized by an anterior lesion of the pelvic girdle with partial disruption of the posterior ring segment (Fig. 17.3). In addition to instability of the anterior pelvic ring segment, the anterior ligamentous structures of the sacroiliac joint are damaged, mostly as a result of an anterior-posterior or a lateral energy impact. The posterior pelvic ring can be affected ipsilaterally, contralaterally, or bilaterally to the anterior lesion. External rotation injuries cause the so-called "open-book" mechanism, whereas internal rotation injuries are the result of a lateral compression with possible impression fracture of the ala of the sacrum or with partial rupture of the dorsal ligamentous structures of the sacroiliac joint.

The lateral compression can impact aslope, yielding a rotation of the affected hemipelvis in the vertical as well as in the sagittal pane. By disruption of additional ligamentous structures, this very unstable Type B injury is often difficult to differentiate from a type C injury. The one hemiplevis can be internally rotated like a handle of a bucket. Therefore, this injury type is termed by Pennal as a "bucket handle" injury.

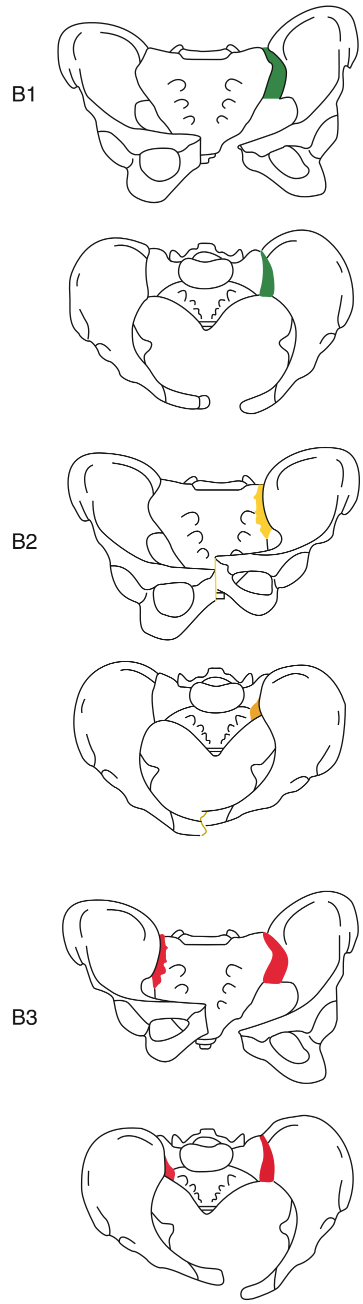

Fig. 17.3 Classification of type-B pelvic ring fractures

Type B 1: External rotation injuries:
Anterior-posterior impact or indirect energy impact transferred via the femur will result in an external rotation of one or both hemipelvis ("open book" mechanism). Type B1.1 and type B1.2 represent

the classical open book mechanism: a disruption of the symphysis of, respectively, less or more than 2.5 cm. In cases of type B 1.3 lesions, there are additional flexion or extension rotational components.

Type B 2: Internal rotation injuries:
Ipsilateral energy impact yields a lesion of the posterior ring segment with internal rotation of the affected hemipelvis. There are often compression fractures of the ala of the sacrum (type B 2.1). Type B 2.2 injury is characterized by partial dislocation of the sacroiliac joint, and type B 2.3 injury shows an incomplete posterior iliac fracture.

Type B 3: Bilateral posterior rotation injury:
Type B 3.1 is characterized by bilateral external rotation injury and type B 3.2 by an internal rotation injury of the one side and, contralaterally, external rotation injury. Type B 3.3 represents a bilateral fracture of the sacrum caused by internal rotation injury.

17.4.2.3 Type C Injuries

The type C injuries are caused by translation or shearing movements of the involved hemipelvis resulting in a complete disruption of the anterior as well as the posterior pelvic ring segment (Fig. 17.4).

Type C 1: Unilateral type C injury–the posterior ring segment is completely interrupted at the iliac bone, the sacroiliac joint, or at the sacrum.

Type C 2: Unilateral type C injury with additionally contralateral type B injury–in cases of increased vertical shear energy impact, the contralateral hemipelvis can be involved by a type B injury of the dorsal ring segment. Depending on the direction of force impact, internal or external rotation injury will result.

Type C 3: Bilateral type C injury–the type C 3.1 injury represents the bilateral extrasacral instability, the type C 3.2 injury is characterized by a combined transsacral and contralateral extrasacral lesion, and the type C 3.3 injury shows a bilateral transsacral instability.

Depending on the potency of the energy impact, smooth transitions are possible between solitary rotational and additional vertical instabilities.

There exist different classifications for *sacral fractures*, which can appear with type A 3, type B, and type C fractures. For clinical daily practice, the classification according to Dennis (Fig. 17.5) has been proved.

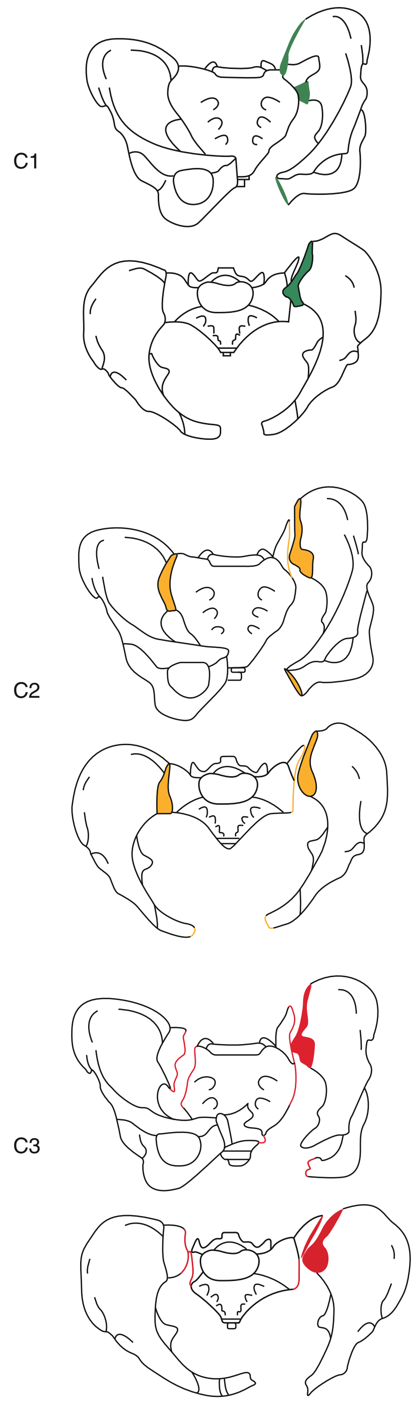

Fig. 17.4 Classification of type-C pelvic ring fractures

This classification is based on three zones in relation to the sacral foramina. It is easy to remember and allows an estimation of the expected rate of neurological damage of the sacral neural plexus. Zone I is located

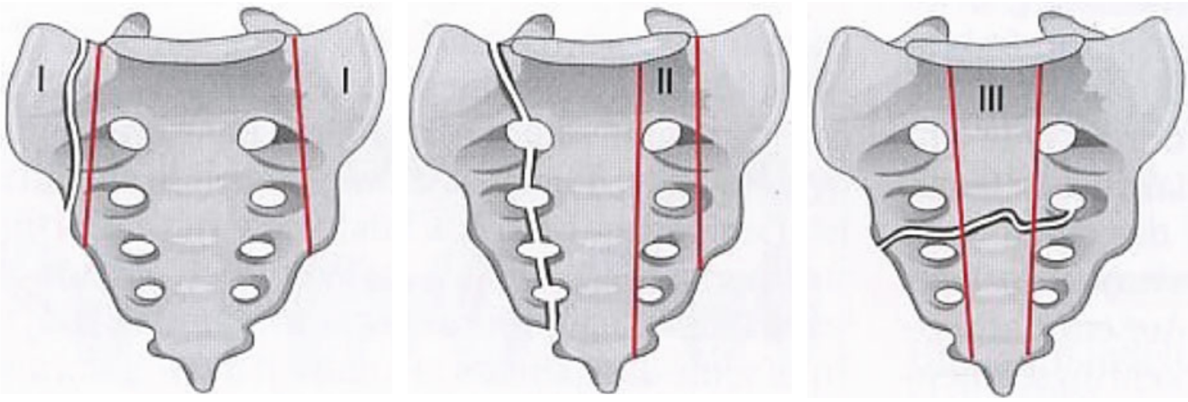

Fig. 17.5 Classification of sacral fractures according to Dennis

laterally and zone III medially of the sacral foramina; zone II is bordered by the sacral foramina. Furthermore, longitudinal fractures, which can proceed from one of the above-called zones, are differentiated from transverse fractures.

17.4.3 Diagnostic Procedures

17.4.3.1 Medical History and Clinical Examination

Because of potentially extensive extravasation of blood volume and concomitant intraabdominal injuries, patients with pelvic fracture may face life-threatening injuries. In principle, the life-threatening situation (polytrauma, complex trauma, crush injury) must be distinguished from the hemodynamically stable situation in solitary pelvic ring injuries without danger to life. The diagnostic procedures as well as the emergency treatment must proceed according to a graduated scheme (ATLS® concept) in polytraumatized patients (Fig. 17.6).

The clinical history, which should essentially consider the injury mechanism, gives primary information for an injury of the pelvic girdle. Clinical examination starts with the inspection of all orifices and concomitant soft tissue injuries (wounds, hematomas, contusions, impalements).

Pelvic ring instability should be tested by gentle but firm compression and distractive movements of the iliac wings. The insertion of a urethral catheter is part of the primary diagnostic procedure. Urethral hemorrhage, scrotal hematoma, and difficult or impossible insertion of the urethral catheter must raise suspicion of a urogenital injury.

When the patient is alert, a precise neurological examination must be performed to exclude neurological damage; its frequency accounts for 11 % in complex trauma and 20–50 % in unstable fractures of the sacrum.

17.4.3.2 Diagnostic Devices

Basic diagnostic procedures include abdominal ultrasound and conventional pelvic X-rays. CT scan and angiography are considered extended diagnostic procedures.

Ultrasound

Ultrasound should be performed immediately in the emergency room. Within several minutes, the whole abdomen can be examined in consideration of free fluid and lacerations of parenchymatous organs (liver, spleen, and kidney). In the pelvis, extended retroperitoneal hematoma as well as peri- or intravesical bleeding or a tamponade of the bladder can be recognized.

Conventional X-Rays

Subsequently, the standard a.p.-view pelvic X-ray is taken. When there is suspicion of involvement of the posterior pelvic ring, additional radiographs using the inlet and outlet technique are performed by tilting the X-ray tube 45°in the frontal plane cranially and caudally, respectively (Fig. 17.7). The inlet view can demonstrate horizontal dislocations, whereas the outlet view shows vertical dislocations. In daily clinical practice, these techniques are being increasingly replaced by the CT scan. However, they are still recommended so as to have a comparison using the

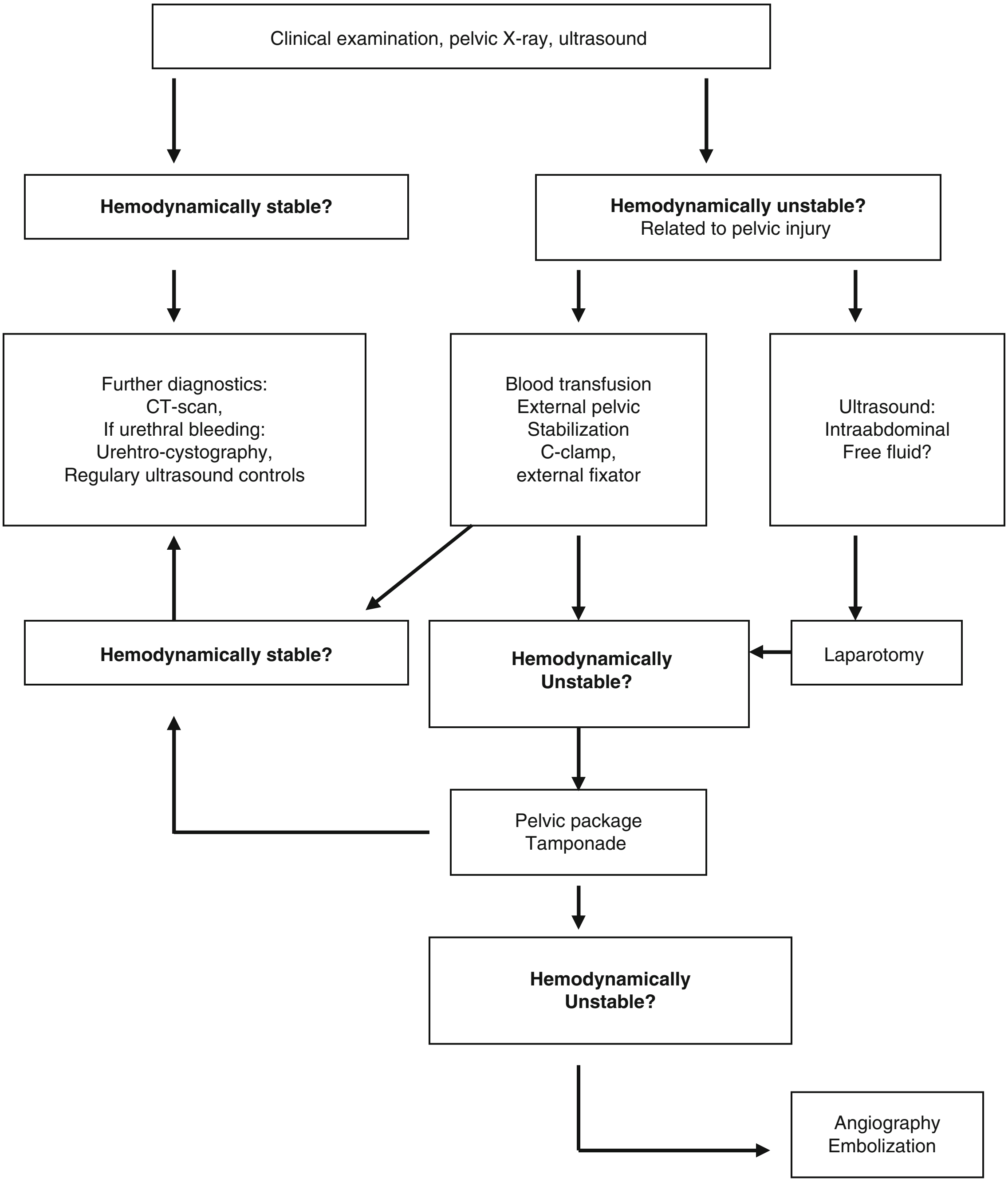

Fig. 17.6 Diagnostics in pelvic trauma

intraoperative image to check the reduction of vertical dislocation in type C injuries.

CT Scan

Only the CT scan is able to visualize the whole dimension of the osseous and ligamentous lesions of the posterior pelvic girdle. The dislocation of fracture fragments and their three dimensional orientation are better visualized than with conventional X-rays. The CT scan enables the severity of the lesion of the posterior pelvic girdle and therefore its classification. Three dimensional CT scan reconstructions improve the

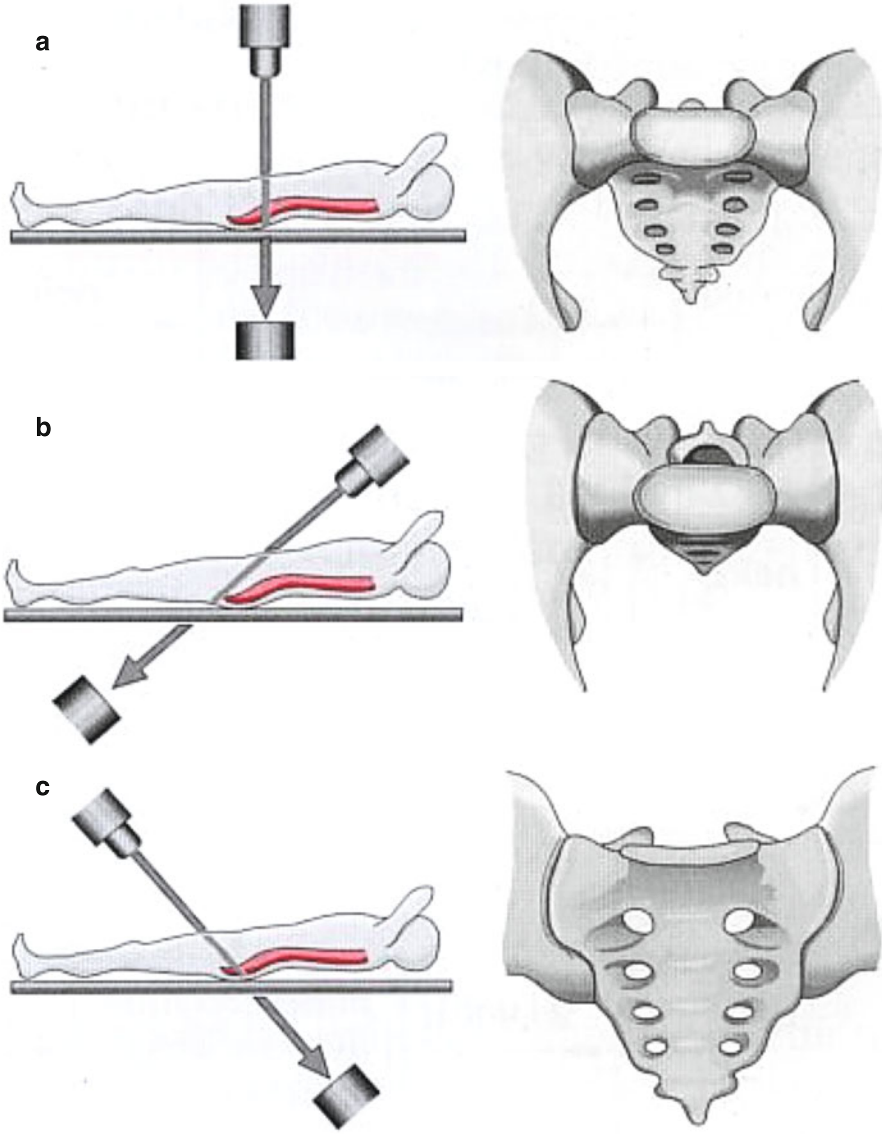

Fig. 17.7 Standard X-rays: (**a**) a.p., (**b**) inlet, (**c**) outlet view

spatial orientation of the fracture lines. By using contrast agents, additional urethral and bladder injuries can be recognized.

Angiography

Angiography is occasionally indicated in cases of persistent hemodynamic instability in pelvic trauma. Using digital subtraction angiography (DSA) technique, intrapelvic bleeding in the area of the internal iliac artery can be visualized if dynamics of the bleeding is greater than 3 ml/min. In the same procedure, the artery can be occluded using coils or gelofoam particles. The value of the angiography is differently discussed. Because the most hemodynamically relevant bleeding has a venous origin, angiography seems to not be indicated. In the own management we attach no importance to the angiography.

When a urethral or bladder injury is suspected, further investigation using contrast agents – retrograde urethrography and cystography – are performed. Rectal examination reveals a dislocation of the prostate (so-called “riding prostate”) in cases of posterior supradiaphragmal urethral laceration.

Following a high-energy impact to the perineum, rectal examination should be followed by a rectoscopy to exclude laceration of the rectum.

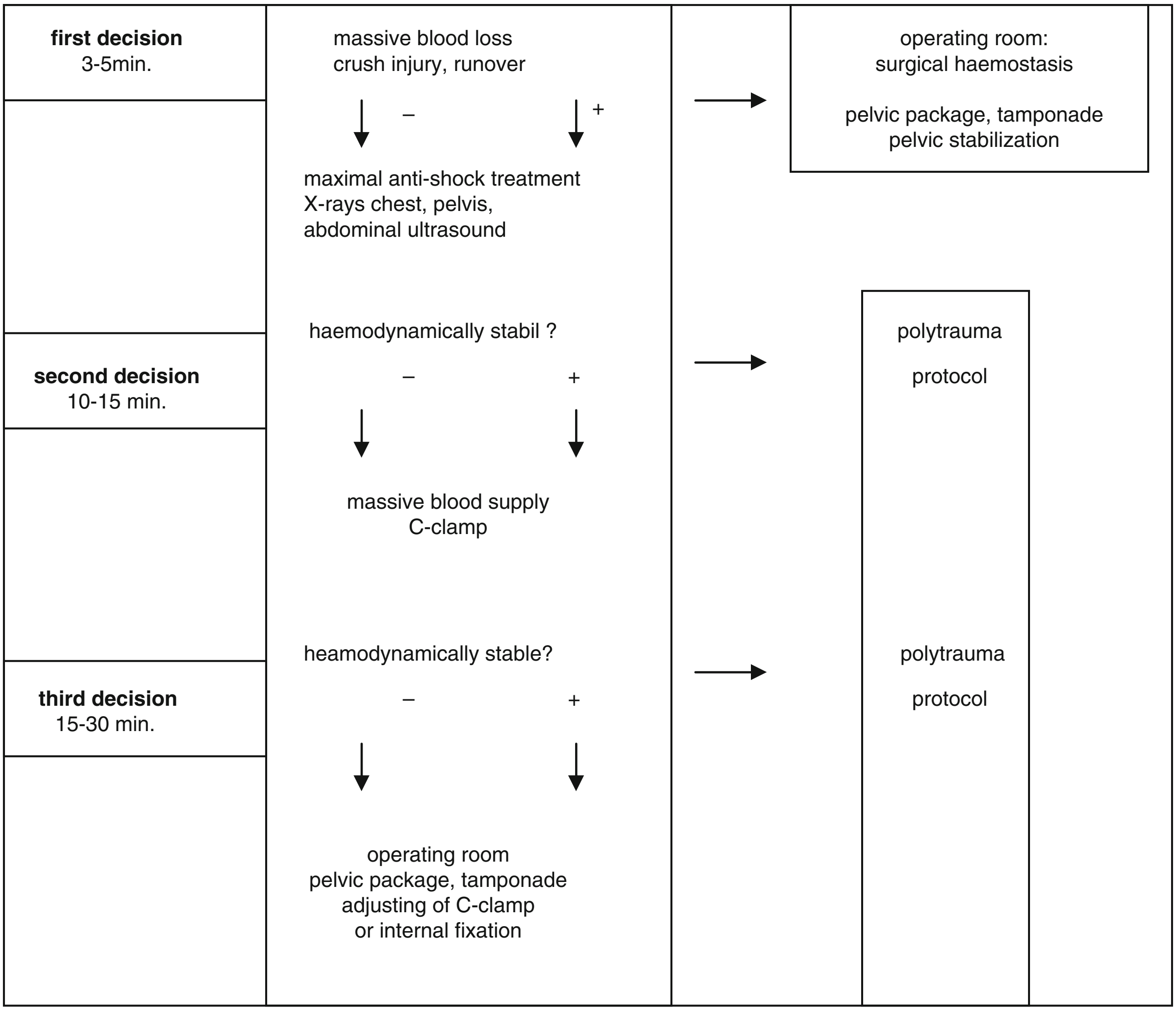

Fig. 17.8 Treatment algorithm in the emergency pelvic trauma

17.4.4 Treatment

17.4.4.1 Treatment Tactics

In addition to appraisal of the stability of the pelvic girdle, differentiation between pelvic fractures without or with life-threatening bleeding is made during the initial treatment phase. In principle, two initial situations can be defined in accordance with the type (direct, indirect trauma, crush injury) and severity of energy impact: the life-threatening emergency situation in cases of complex trauma or crush injury with hemodynamic instability and the solitary osseous or ligamentous injury without hemodynamic effects.

17.4.4.2 Treatment Concepts in Emergency Cases

Patients with pelvic ring injuries and life-threatening hemorrhages (hemoglobin < 8 mg/dl on arrival at the emergency room) should be managed according the "pelvic emergency algorithm" (Fig. 17.8). In cases of massive obvious hemorrhages following crush injuries or run-over, patients will be rushed to the operating room for emergency surgical procedures and, if necessary, emergency hemipelvectomy. In cases of life-threatening hemorrhages, where the source of bleeding is not obvious, it may be wise to initiate shock treatment and apply massive fluid challenge. When the patient is not responding to these procedures and is not in a hemodynamically stable condition within 10–15 min, self-tamponade of the bleeding into the retroperitoneal space cannot be assumed. These cases must be addressed by giving O negative packed red cells, and the pelvic girdle should be stabilized mechanically by external procedures to reduce the intrapelvic space. Bleeding caused by the cancellous bone and by the posterior sacral and anterior perivesical venous plexus will be compressed. The C-clamp (Fig. 17.15) is the appropriate external stabilizer for type C injuries. In cases of open-book injuries, the pelvic girdle can be closed using an anterior external fixator (Fig. 17.16).

In continuous hemodynamic instability passing the next 15–30 min, the patient should be transferred to the operating room to perform a packing tamponade. The incision is performed from the symphysis to the umbilicus. Extraperitoneal inspection of the pelvis follows. Massive hematoma is evacuated and the true pelvis is packed with tamponades at both sides of the bladder to the posterior presacral region. Packing is only helpful when counterpressure can be established after external stabilization of the pelvic ring. If necessary, the C-clamp should be adjusted. The anterior pelvic ring is stabilized by a single internal fixation (plate or tension band wiring). The definitive stabilization and reconstruction of the posterior pelvic ring may be performed secondarily if applicable during a second-look procedure of the pelvic package.

Using military anti-shock trousers (MAST) for external compression of the pelvic girdle does not avoid dissemination of the hematomas and, furthermore, may increase the danger of a severe compartmental syndrome. The MAST suit makes also the artificial ventilation and the clinical handling of the patient difficult. Therefore, this equipment has no relevance in this situation.

17.4.4.3 Treatment Concept in Pelvic Injuries Without Hemodynamic Instability

Operation Time

All pelvic girdle injuries requiring stabilization will be operated on as soon as possible when control of hemorrhage and protection of the soft tissue are ensured.

Nonoperative Treatment

Stable pelvic ring fractures (type A injuries) can be treated nonoperatively. Fractures of the pubic rim, undisplaced iliac wing fractures, transverse fractures of the sacrum below the linea terminalis, and in zone I according to Dennis require only a short time of bed rest until relief of fracture pain is attained. Avulsion fractures of the iliac spine or of the ischial tuberosity can also be treated nonoperatively. The leg is carried in the corresponding unloaded position for 1–2 weeks. Avulsion of the inferior anterior iliac spine heals without problems because the alteration of the length of the muscle can be completely compensated. This can also be applied to the avulsion of the ischial tuberosity; the hip joint is carried in an extension position to relax the hamstrings. Internal fixation using lag screws, tension band wiring, or transosseous sutures is recommended only in active athletes.

In type B and C fractures, internal fixation is not often performed. Nonoperative treatment is possible but its result is a high percentage of deformities of the pelvic ring. The often painful instability of the ligamentous injury will lead to a poor clinical outcome. Therefore, internal fixation is considered as the standard and, therefore, pelvic ring injuries should be admitted to a trauma center.

Operative Treatment

Surgical treatment with internal fixation in cases of unstable type B and C fractures enables anatomical reconstruction of the pelvic girdle, resulting in possible weight bearing and in a reduction of the immobilization phase.

Indication for open reduction and internal fixation can also been seen in type A fractures, such as major dislocations of iliac wing or pubic rim fractures that are dangerous to vascular, neural, or bladder lesions (so-called “tilt-fracture”).

Fixation Tactic

The principle of internal fixation in type B fractures is the closure of the anterior pelvic ring. Transsymphyseal instabilities always require open reduction and internal fixation by plate. Transpubic instabilities can be fixed by an external fixator or by transpubic screws. In cases of additional external or flexional instability (type B 1.3, type B 2.3 injury) stabilization of the posterior ring may be necessary.

In type C injuries, the anterior as well as the posterior pelvic ring has to be reconstructed. Only in cases of minor instability of the anterior pelvic ring (in the context of an internal rotation injury) can the anterior stabilization be renounced (Fig. 17.9).

Stabilization of the Anterior Pelvic Ring

The most common indication for stabilization of the anterior pelvic ring is the rupture of the symphysis.

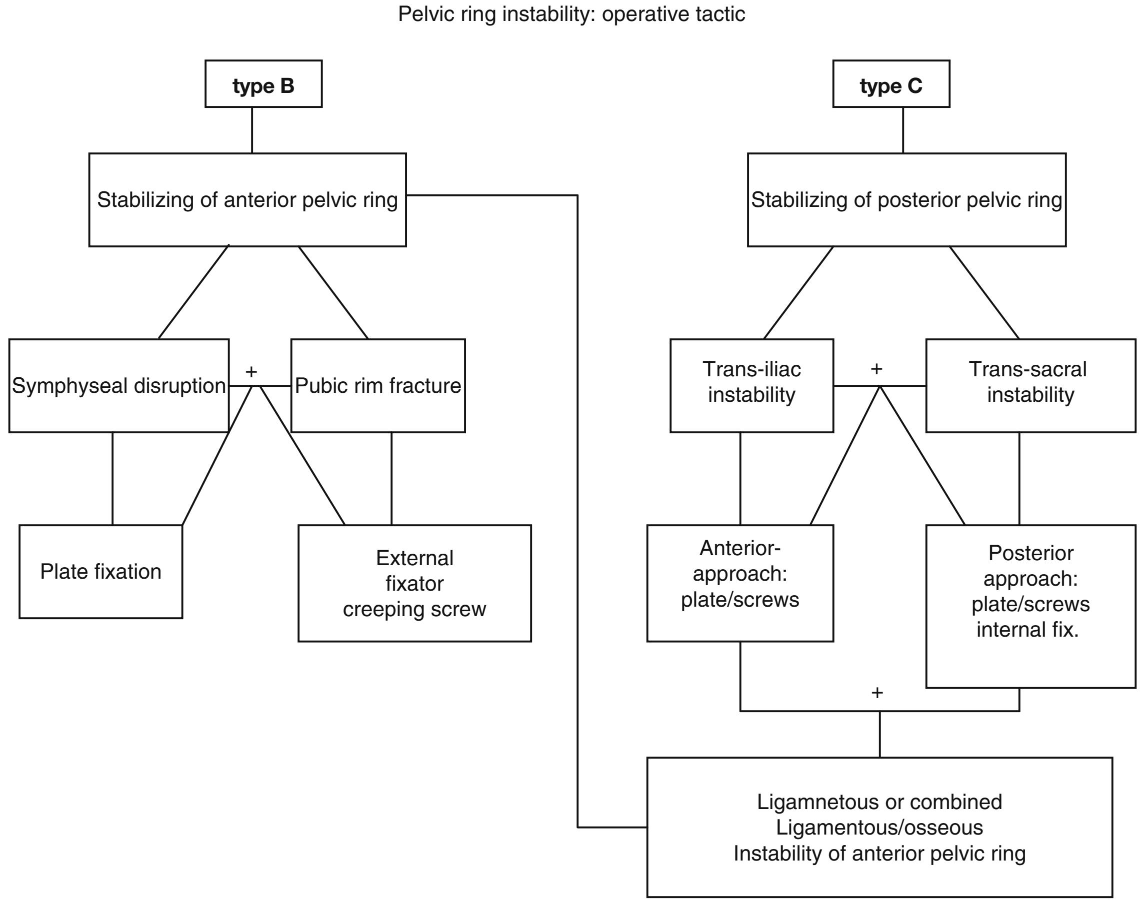

Fig. 17.9 Operative tactic in type-B injuries and in type-C injuries

Approach

In cases of isolated transsymphyseal instability, a Pfannenstiel approach is performed; in cases of laparotomy, via a median longitudinal laparotomy.

Required stabilization of transpubic instabilities is achieved via minimally invasive medial incisions. The complete exposure of the pubic rim is not necessary and increases the risk of damage of the femoral nerve and vessels. Both rectus abdominis muscles are engrailed at both sides only as much as necessary. The cavum retzii before the bladder becomes obvious. During wound closure, exact refixation of the abdominal muscles is mandatory to avoid a hernia.

Operation Technique

Small, 4.5-mm DC plates are normally used for fixation. A flush closure of the symphysis should be attempted. A sharp reduction clamp into the obturator foramen can be used for reduction. The plate is located at the cranial area of the pubic rims (Fig. 17.10). Normally, four-hole, 4.5-mm plate and cortical screws are used. The direction of drilling is 30° to the vertical plane dorsally and caudally. In children, tension band wiring over two screws near the symphysis can be performed alternatively.

In unstable fractures of the pubic rims, screw fixation can be carried out. Cortical screws are inserted via small medial incisions. Because only the medial cortex is drilled, the screws are creeping intramedullary (so-called "creeping screws") and work as a lag screw when passing the fracture line.

Stabilization of the Posterior Pelvic Ring

In type C injuries, the approach is determined by the site of the instability. Depending on the site of instability, the soft tissue damage, and concomitant injuries, the stabilization is performed via an anterior-lateral or via a dorsal approach (open or closed). Transiliac

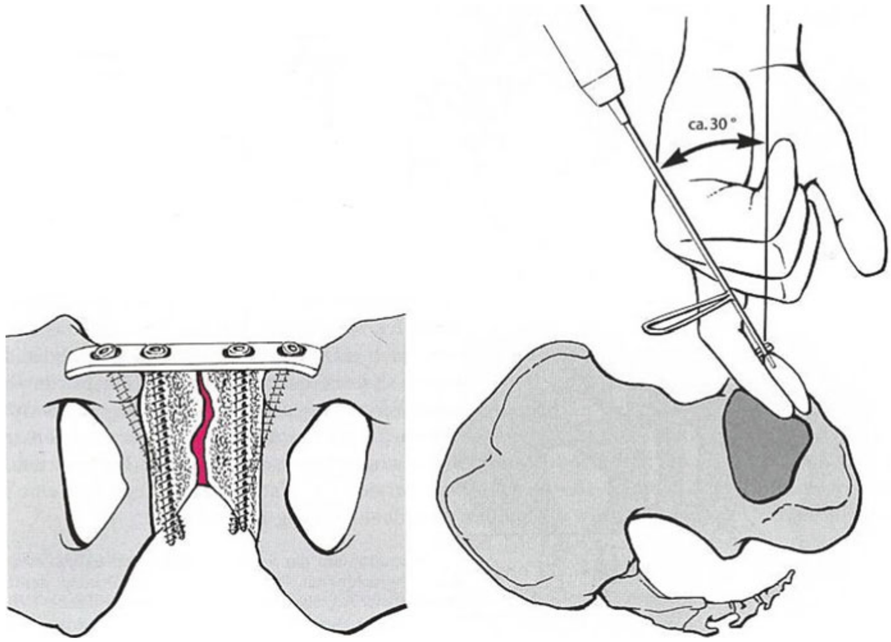

Fig. 17.10 Fixation of symphysis: localization of the plate and direction of drilling

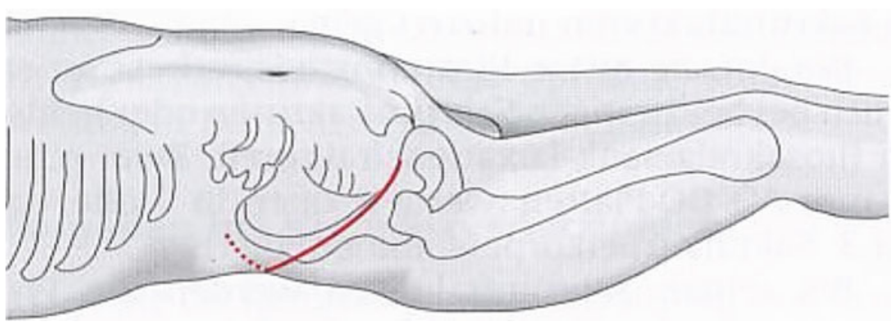

Fig. 17.11 Anterior-lateral approach to the posterior pelvic ring

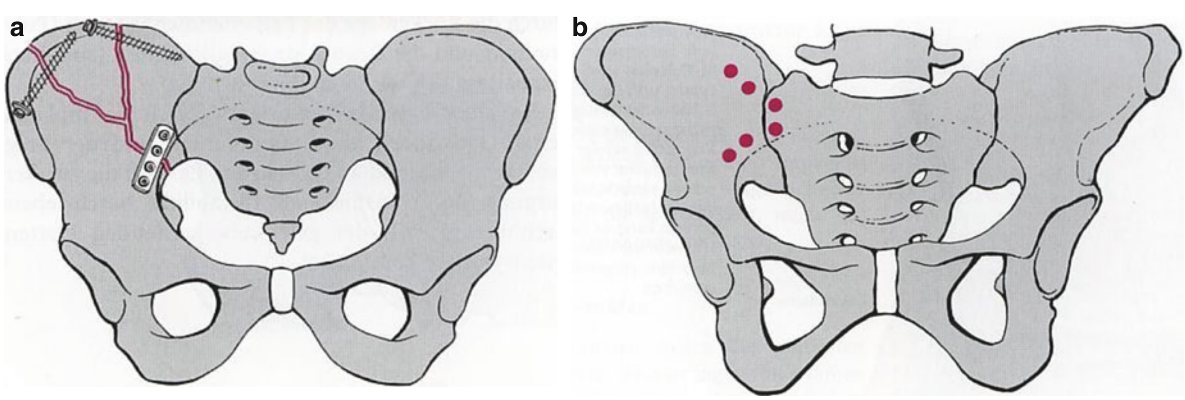

Fig. 17.12 Stabilization by plate of iliac (**a**) and sacroiliac (**b**) instability

instability is approached anterior-laterally (Fig.17.11). Stabilization can be performed using plates and screws (Fig. 17.12a). The anterior-lateral approach is also feasible for sacroiliac dislocation (Fig. 17.12b) and for transsacral instability with a small anterior fracture fragment of the sacrum.

The posterior approach is reserved for fractures of the sacrum, for bilateral sacroiliac dislocations, and for situations with previous colostomy. The lack of possibility of simultaneous reduction of the anterior pelvic ring is considered as the disadvantage of the posterior approach.

Anterior-Lateral Approach

This approach is performed with the patient in the supine position medially to the iliac crest (Fig. 17.11). The psoas muscle is retracted medially by subperiosteal preparation. Below the transversal process of the fifth lumbar vertebral body, the first radix of the sacral plexus becomes obvious. Because of narrowness, reduction clamps cannot be used near the sacroiliac joint. Therefore, reduction must be achieved indirectly via traction, abduction, adduction, or rotation of the leg. If applicable, tension band wiring over two screws inserted at both sites of the sacroiliac joint may be helpful for reduction. The reduction is controlled by direct visualization, by the palpating finger, and by the image intensifier in the a.p., inlet, and outlet view (Fig. 17.7).

Operation Technique

Stabilization via the anterior-lateral approach is performed by two short (3- or 4-hole) small fragment, 3.5-mm reconstruction plates. The plates must form an angle of 70–80°, where the cranial plate is located at the upper iliac crest, and the caudal plate is placed along the linea terminalis. The so-called "parallelogram effect" should be avoided (Fig. 17.12b).

Posterior Approach

The posterior approach is performed with the patient in the prone position, 1.5 cm laterally to the posterior iliac spine along the posterior iliac crest. The gluteal fascia is cleaved, and the gluteal muscles are retracted laterally. The preparation is continued distally to the sciatic notch. The gluteal vessels must be protected from damage. In the case of vertebro-pelvic internal fixation (see below), a paraspinal approach is performed. The incision starts 6–8 cm laterally of the center line at the fourth lumbar spine level up to the posterior iliac crest. The paraspinal approach is also used for local internal fixation of the sacrum. In cases of bilateral lesions, a median approach to the sacrum is chosen. The paraspinal musculature is dissected caudally from the sacrum, and the flap is retracted to cranially.

Operation Technique

The reduction of sacroiliac dislocation can be achieved using a sharp reduction clamp or a Jungbluth clamp fixed at two screws that are inserted at both sites of the sacroiliac joint. The reduction can be controlled by the image intensifier using the inlet and outlet view or by the palpating finger into the sciatic notch.

Two 7.0- or 7.3-mm cannulated, middle-threaded (i.e., 32 mm) cancellous screws are satisfactory for trans-sacroiliac screwing. The screws are anchored into the first vertebral body of sacrum. The entry point lies about 3–4 cm laterally from the posterior iliac crest. In the frontal plane, the screws are inserted at a 10° angle, that is, vertically to the plane of the iliac wing (Fig. 17.13). To avoid vascular damage, perforation of the anterior cortex of the sacrum is not allowed. Closed reduction and trans-sacroiliac screwing is increasingly performed by image control in cases of closely reducible sacroiliac dislocation or transsacral lesions.

The closed trans-sacroiliac screwing is more easily carried out with the patient in supine position. The entry point is defined by image control in the lateral view. The outlet view shows the exact level, whereas the inlet view controls the angle to the frontal plane.

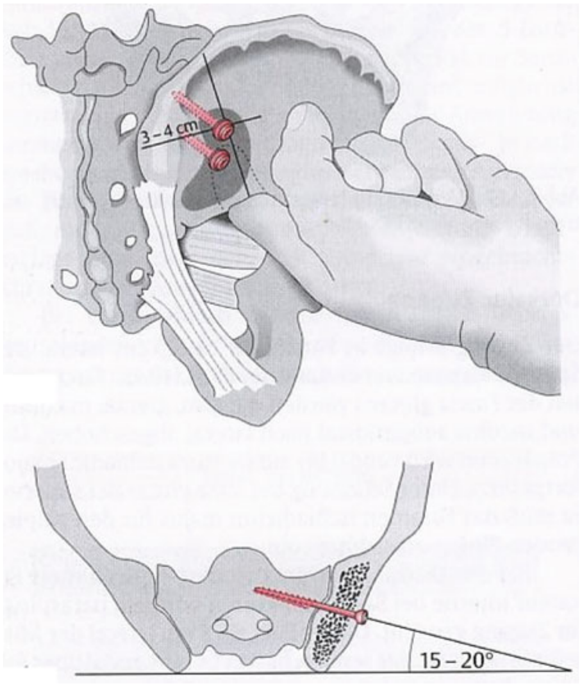

Fig. 17.13 Trans-sacroiliac screwing

In cases of transsacral lesions, the direction of drilling is less than 10°, preferably parallel to the frontal plane to obtain a safe anchorage into the first vertebral body of sacrum.

In cases of posterior transiliac fractures with a small iliac fragment, it is also possible to fix the sacroiliac joint with a shaped reconstruction plate. Caudally, the plate is anchored into the sacrum. This fixation type can also be indicated in transalar sacral fractures.

The posterior transverse plate fixation is required for bilateral fractures of the sacrum or bilateral dislocations of the sacroiliac joint. Two small 4.5-mm DC plates are shaped at the first and the third level of sacrum. The fixation is achieved in the posterior iliac spine or in the ala laterals of sacrum. Transverse thread rods through the posterior iliac spines have not been proven.

In cases of transforaminal sacral fractures at the level of S1 and S3, adapted small fragment implants (H-shaped plate) can be placed directly to the fracture (so-called "local internal fixation"). The fixation is performed via the pedicles and laterally through the ala laterals of sacrum. By this fixation technique the rotational forces of solitary trans-sacroiliac screwing are reduced, but the stabilization of the anterior pelvic girdle is necessary to provide the tension band effect. In cases of neurological deficits, laminectomy or foraminectomy must be performed for decompression of the sacral roots.

Alternatively, in cases of major displaced sacral bursting fractures – mostly due to a fall from a great height (so-called "suicidal jumper's fracture") – a vertebro-pelvic fixation by an internal fixator can be performed. The pedicular screws are anchored into the pedicle of the fifth lumbar body and into the posterior iliac spines (Fig. 17.14). Reduction of the fracture can be achieved by traction via the longitudinal support of the internal fixator (so-called "distraction osteosynthesis"). Additional trans-sacroiliac screwing will increase the rotational stability.

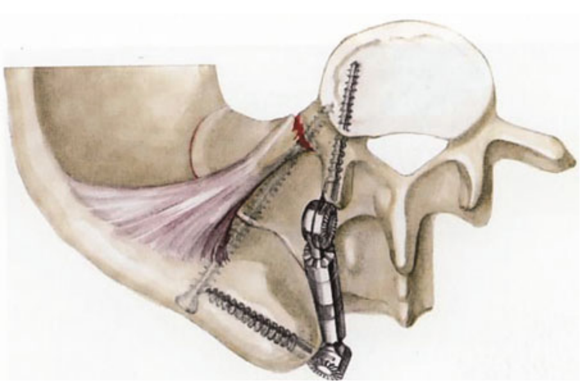

Fig. 17.14 Vertebro-pelvic stabilization by internal fixation

Complex Trauma

The treatment concept of complex trauma and crush injuries is mainly determined by the extensive, life-threatening blood loss. The graduated scheme according to the pelvic algorithm (Fig. 17.11) has to be respected.

In cases of urethral or bladder injuries or perianal impalements, further specialists are called in. Bladder lacerations require an immediate primary care. In doing so, the anterior pelvic fracture is stabilized. If there is no emergency intervention necessary, urethral injuries are treated with a suprapubic tube. Secondarily, together with the urethral reconstruction, the anterior pelvic ring is stabilized.

In cases of perianal impalements with rectal laceration, a double artificial anus has to be constructed at the transverse or the sigmoid colon. Disruptions of the anal sphincter have to be reconstructed as soon as possible, because identification of the anatomical structures may shortly be difficult. Rectal wash-out must be performed repeatedly to avoid septic complications.

Injuries of the vagina can normally be reconstructed by primary suture. The urethra is splinted by a transurethral catheter.

Extensive contusions of the musculature, unevacuated hematomas, and subcutaneous décollements (Morel-Lavallée syndrome) can result in soft tissue infection that is difficult to treat and even in multiple organ failure. Aggressive debridement and, if necessary, multiple second-look procedures are required.

In cases of necessary laparotomy or pelvic packing, the anterior pelvic ring is stabilized in the manner described above. The definitive stabilization of the posterior pelvic ring is performed secondarily.

The stabilization of the posterior pelvic ring in an emergency can be achieved by the C-clamp or by an external fixator.

C Clamp

The C-clamp according to Ganz is indicated to approximate emergency reduction and compression of the posterior pelvic ring in cases of extensive blood loss.

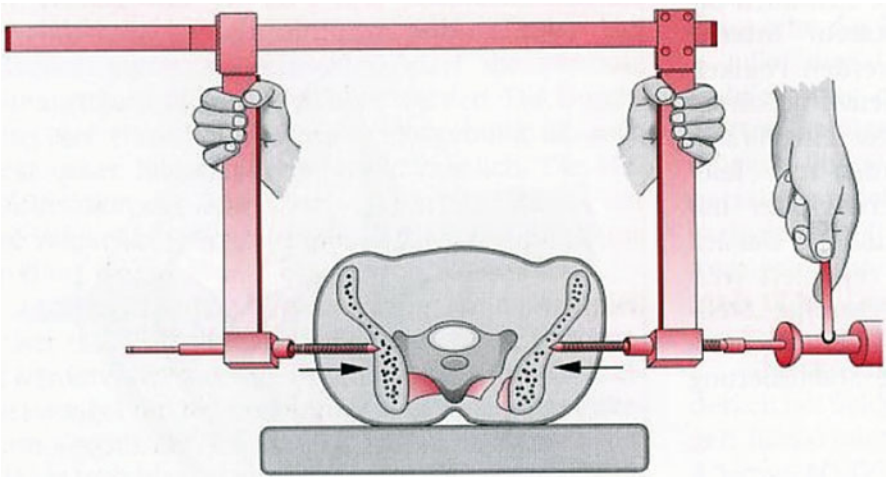

Fig. 17.15 C-clamp according to Ganz

Operation Technique: The C-clamp, working like a carpenter's clamp, is placed at the intersection of a line between the anterior and posterior iliac spine and the elongation of the posterior border of the femur (Fig. 17.15). If the clamp is inserted too far distally, the sciatic nerve into the sciatic notch is endangered. Too much ventral positioning offers the risk of perforation of the thin iliac wing. The threaded tube is then tightened and the posterior pelvic ring is compressed and solidly fixed. Steinmann pins can be placed into the iliac crest for additional manipulation.

External Fixator

An external fixator can also be used for emergency stabilization of the pelvic ring. But permanent stabilization, especially of the posterior pelvic ring, cannot be achieved; therefore, the definitive treatment with the external fixator is an exception (such as in case of poor soft tissue). The risk of infection of the pins with consequent loosening and of osteomyelitis of the iliac wing is high. An external fixator assembled at the supraacetabular region can be used for fixation of the anterior pelvic ring in cases of type B or type C lesions (such as transpubic instability associated with sacral fracture).

Operation Technique: Reduction and retention are performed with one or two Schanz screws at each side. The cranial screws are inserted into the iliac crest; the caudal screws are placed at the compact bone of the supraacetabular region near the anterior inferior iliac spine. Corresponding to the inclination of the iliac wings, the screws are drilled in a 45–60° angle. Rotational displacement caused by the fracture must be noticed. After connecting two pins on each side, the assembly can be used as a lever for reduction before the longitudinal rods are added. Adequate distance to the abdominal wall must be maintained, because an increase of the abdominal volume caused by bowel ventilation disorders must be anticipated (Fig. 17.16).

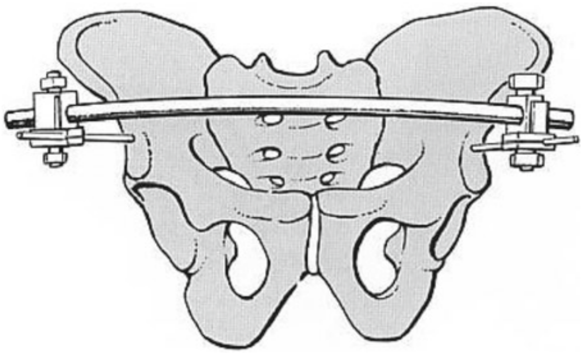

Fig. 17.16 Assembling of external fixator

17.4.5 Treatment of Pediatric Pelvic Ring Injuries

The special feature of the pediatric pelvic ring is characterized by its elasticity associated with possible plastic deformation. In contrast to adults, there is a minor protection for intraabdominal organs. Therefore, pediatric pelvic ring fractures or ligamentous lesions are always a sign of a major energy impact. Simple fracture types have produced extensive lesions of intraabdominal organs.

Pediatric pelvic ring injuries are also classified according to the above-mentioned principles. The following treatment methods exist:

- Nonoperative treatment
- External fixator
- Internal fixation techniques

The treatment method is essentially determined by and there are the following questions:

- Is there a polytrauma?
- Is the pelvic ring stable?
- Is there a rotational (type B) or a vertical (type C) translation instability?
- Is the acetabulum involved?
- How dislocated are avulsion fractures of the apophyses?

17.4.5.1 Fractures of the Iliac Wing or Avulsion Fractures of the Apophyses

Open reduction and internal fixation are only necessary in cases of major displacement. This also applies to avulsion fractures of the ischial tuberosity or of the inferior anterior iliac spine. When open reduction and internal fixation are necessary, tension band wiring or screw fixation are usually performed. However, bed rest for 2–3 weeks is usually sufficient, with corresponding unloading position of the leg (i.e., extension in cases of avulsion of the ischial tuberosity to relax the hamstrings, and flexion in cases of avulsion of the inferior anterior iliac spine).

17.4.5.2 Pelvic Ring Fractures

Type B injuries: Rupture of the symphysis is extremely rare in childhood. The physiologically different widths of the symphysis must be respected (e.g., 10 mm in a 3-year-old child, 3 mm in a 20-year-old man). Plate fixation using age-adapted implants or tension band wiring can be performed. In children less than 3 years old, transosseous sutures may be sufficient. Alternatively, an external fixator can be used, which shows the definitive supply when a proper reduction is feasible.

Type C injuries: The fixation method in type C injuries is dependent upon the possibility of reduction and durable retention. Major displacements should be avoided, especially in girls. Correct length of the legs must be attained. External fixators and, alternatively, plates can be used for fixation.

17.4.6 Postoperative Treatment

Because the risk of thrombosis is increased in pelvic injuries, prophylactic physical and medicamentous procedures must start immediately. A single shot of antibiotics is also recommended. Depending on the soft tissue damage (crush or open injury), antibiotics may need to be continued.

Generally, the surgeon determines the beginning of mobilization. In cases of stable internal fixations, partial weight bearing (15–20 kg) of the affected side is feasible immediately. Partial weight bearing is also recommended for type B2 and type B3 injuries, which are anteriorly stabilized, and for posteriorly fixed type C injuries. Full weight bearing is allowed in stabilized disruptions of the symphysis (type B1 injury).

There exist different opinions about weight bearing after definitive treatment with an external fixator. When the posterior pelvic ring is stable, immediate full weight bearing is feasible.

X-ray controls in the a.p., inlet, and outlet view are recommended postoperatively and after 6 and 12 weeks.

In complex trauma or crush injuries, the course of soft tissue contusions demands attention. Multiple second-look procedures and debridements can be necessary. In cases of an artificial anus, daily rectal washout has to be performed.

Removal of implants is recommended in the plate of the symphysis, because the physiologic symphyseal movement will cause loosening of the screws. Healing of symphyseal rupture will take at least 4 months; implants should not be removed before 6 months. The authors usually do it after 12 months. Trans-sacroiliac screws are also removed after this interval. All other implants are only removed when they cause pain (e.g., caused by the loosening of screws)

17.4.7 Complications

General complications include deep thrombosis (incidence 7–10 %), pulmonary embolism (incidence 2–3 %) and multiple organ failure following complex trauma or crush injury (incidence up to 10 %).

Local complications are observed predominately as hematoma and infection, with an incidence of 6–7% relating to all cases and of 20–25 % relating to complex trauma.

Nerve damage, mostly affecting the sciatic nerve, is seen in 8–10 %; half of this damage becomes permanent.

As expected, the highest rate of neural lesions in seen in cases of transforaminal fractures of the sacrum (incidence 28 %).

Dangerous intraoperative bleeding can result from a laceration of the superior gluteal vessels when stabilizing the posterior pelvic ring or of the obturator artery in anterior procedures.

The estimates of incidence of secondary displacement of internal fixed fractures vary between 2 and 10 %.

As *late complications,* painful disorders of the sacroiliac joint are seen in 27 %, painful nonunions and instabilities are recorded in 3.2 %, whereas healing of the fracture with misalignment is found in 5–8%. Relevant difference of the length of the leg (> 2 cm) is seen in 3–6 % of the type C injuries.

Sexual disorders are observed in 10 % of males and 2 % of females. The rate of impotence is about 50–60 % in urethral lesions, which are seen in 5 % relating to all fractures and in about 50 % relating to complex trauma.

17.4.8 Late Reconstructive Procedures

Nonunions, persistent instabilities, and misalignments can result in painful weight bearing, in a shortening of a leg, and in a misalignment of the acetabulum with consequent dysbalance of the pelvic musculature. Pelvic deformities can also yield an obstacle at delivery. In cases of fractures of the sacrum, extremely painful neurological deficits can remain permanently. Misalignment of a pubic rim fracture can result in mechanical disability of the bladder, compromising micturition.

Avulsion fractures followed by extensive callus formation can cause an impingement of the hip joint with consequent restricted motion.

Diagnostics require accurate neurological and urological examinations, conventional X-rays in the a.p., inlet, and outlet view, and the CT scan. Three-dimensional reconstruction of the CT scan may be helpful to recognize malrotation, malflexion, or cranial migration of one or both hemipelvis.

The surgical approaches correspond to those of primary care. The treatment of pelvic misalignments represents a high surgical demand. The reduction of the misaligned fragment can be extremely difficult, in most cases requiring an osteotomy.

17.4.8.1 Malhealing

Type C injuries with relevant shortening of the leg (i.e., <2 cm) should be revised. The often necessary three-dimensional correction should be reserved for special centers. Iliac and pubic osteotomies at the level of misalignment are necessary for reduction.

Bilateral misalignments of sacral lesions often require a bilateral posterior iliac osteotomy and distraction of the pelvis against the spine. Vertebropelvic stabilization using an internal fixator can be performed.

Persistent neurological deficits following unreduced transforaminal fractures of the sacrum can sometimes be improved by late decompression of the sacral roots; fractures of the spinal canal can sometimes be improved by performing a laminectomy.

In cases of impingement of the urinary bladder resulting from a displaced pubic rim fragment, resection of the corresponding bone fragment will mostly suffice.

17.4.8.2 Nonunions and Instabilities

Whereas extensive misalignments can remain without symptoms, posterior nonunions and instabilities especially may cause permanent painful disorders. In most cases, persistent ligamentous instabilities of the sacroiliac joint and of the symphysis are the cause. Instabilities of the symphysis that stress only one leg can be detected by X-rays. Displacement of more than 2 cm is considered as pathologic. Fixation of an unstable chronic symphysis should be performed with two ventrally, orthographically placed plates. Cancellous or corticocancellous bone graft is required for definitive symphysiodesis. Depending on the localization, anterior or posterior techniques are necessary for treatment of nonunions or instabilities of the posterior pelvic ring. Anterior standard fixation techniques are sufficient for iliac nonunions. Nonunions of the sacroiliac joint require an arthrodesis with spongy bone graft. The anterior double-plate fixation offers the best stability in these cases.

17.4.9 Prognosis

The results of the multicenter study of the AO International and the German Trauma Society (study group pelvis) confirm that pelvic ring fractures heal anatomically in 80 % of patients provided that adequate conservative or operative treatment is performed. However, only two-thirds of all fracture types reveal a good or excellent clinical outcome. This discrepancy may be due to possible concomitant neurological and urological injuries or to ligamentous disorders. Not all poor clinical results are clearly understood. The overall clinical result is mainly dependent upon the severity of the injury and upon the concomitant injuries. The overall lethality is 5 % for isolated pelvic ring fractures, 20 % relating to complex trauma, 33 % for patients admitted with hemodynamic instability, and 60 % for crush injuries.

Persistent pain can be observed in 10–30 % of patients with type A injuries, in 15–40 % after type B injuries, and in 30–45 % after type C injuries or complex trauma.

Radiological results are good in 100 % of type A, 90 % of type B, and 70–80 % of type C injuries.

The overall clinical result is mainly determined by pain and by neurological and urological deficits. Good and excellent results are seen in 65 % of type A injuries, 75 % of type B injuries, 55 % of type C injuries, and 40 % of complex trauma.

Unmodified lifestyle as a measure for social reintegration is observed only in 45 % of patients with type A injury, 48.6 % with type B injury, 23 % with type C injury, and 21 % of patients with complex trauma (Table 17.3).

One reason for the unexpected poor results for patients with Type A injury may be the frequent inclusion of elderly patients in that group. The analysis of further prognostic parameters, which determine the clinical outcome, is incomplete. The following parameters seem to be of importance: “complex trauma,” “type C injury,” “involvement of the sacroiliac joint,” and “fracture of sacrum.”

Table 17.3 Results after pelvic ring injuries (study group pelvis of AO)

Fracture type	Good and excellent results		Unmodified lifestyle (social re-integration) (%)
	Radiological (%)	Clinical (%)	
Type A	100	65	45
Type B	90	75	48
Type C	70–80	55	23
Complex trauma		40	21

17.5 Acetabular Fractures

Within pelvic injuries, acetabular fractures must be considered independently. Remaining steps or gaps within the loading area of the acetabulum can result in premature arthritis of the hip joint. Therefore, exact reduction and stabilization is necessary to avoid arthritis or to decelerate its process, provided that the cartilage is not damaged by the trauma.

17.5.1 Injury Mechanism

In 50–80 % of pelvic injuries there is polytrauma. Solitary fractures of the acetabulum are found in about 20 % of all pelvic injuries; in 15 % the acetabular fracture is associated with pelvic ring injury. In most cases, there is a direct or indirect (transferred via the femur) energy impact. The latter mechanism is seen both in falls from a great height and in dashboard injuries.

17.5.2 Classification

For acetabular fractures, different classifications exist, all based upon the theory of two columns. Letournel and Judet have worked out a precise radiological anatomy for this purpose.

The *classification according to Letournel and Judet* has been established. There are 10 different fracture types, 5 elementary fracture types with 1 major fracture line, and 5 different combined fracture types composed of at least 2 elementary fracture types (Fig. 17.17).

The AO classification differentiates one-column fractures (type A), transverse fractures (type B), and two-column fractures (type C). However, this classification does not approach the fracture’s morphology and, therefore, is not used today.

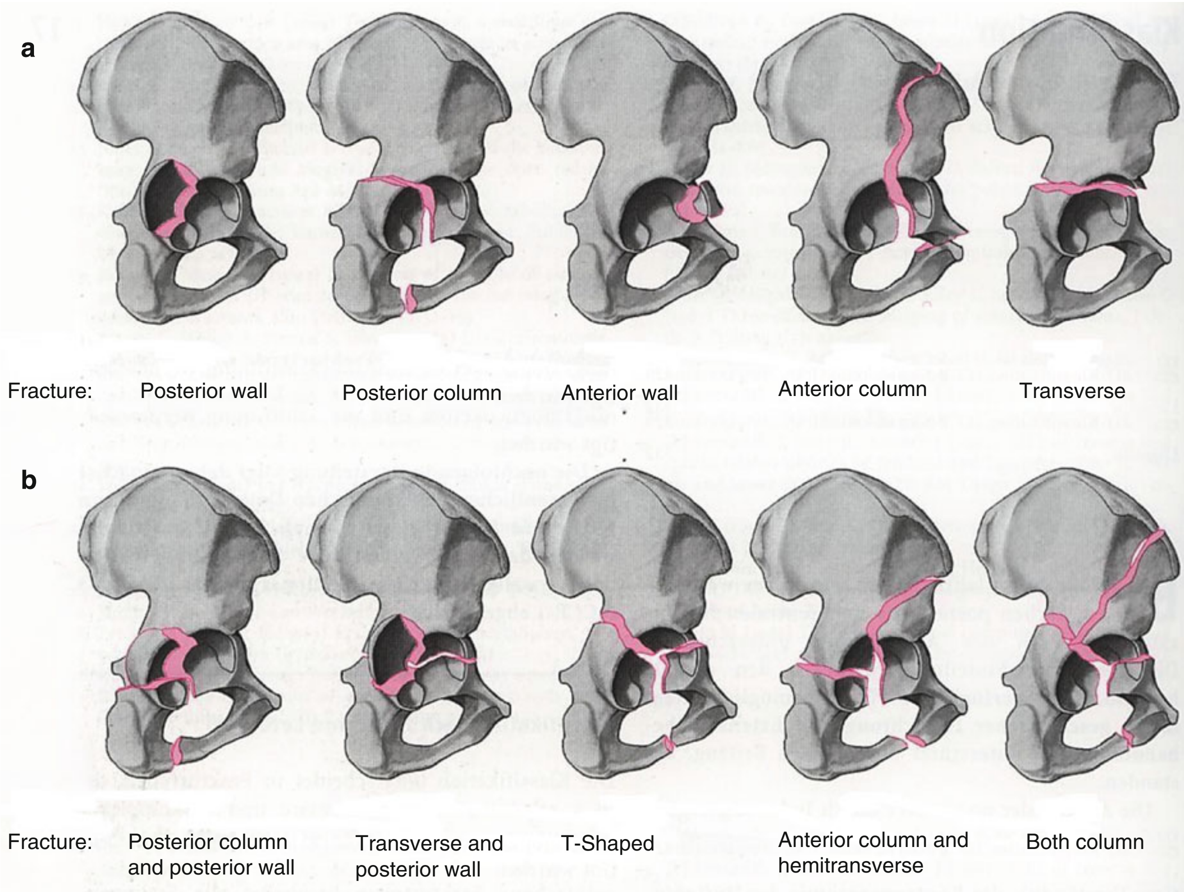

Fig. 17.17 Classification of acetabular fractures according to Letournel and Judet

17.5.2.1 Elementary Fracture Types

Posterior wall fracture: This is the most frequent acetabular fracture type, which is often caused by a posterior dislocation of the hip. In about one-third of cases, there is a large solitary fragment; in about 20 %, additional impressions of the articular surface are seen.

Posterior column fracture: The posterior column is completely disconnected from the acetabulum. The fracture line crosses the obturator foramen toward the inferior pubis rim. The femoral head is mostly dislocated inwardly.

Anterior wall fracture: This fracture type is extremely rare. It results from an energy impact to the externally rotated leg.

Anterior column fracture: This fracture type is one of the most common. In contrast to the anterior wall fracture, this fracture is characterized by starting above the inferior anterior iliac spine, passing through the obturator foramen.

Transverse fracture: The fracture line crosses the acetabulum horizontally. Both columns are involved. Depending on the level of the fracture, there are infratectal, juxtatectal, and transtectal fracture types. In the majority of cases, the causal part of the acetabulum is presented internally rotated. The main dislocation is usually found at the posterior column.

17.5.2.2 Combined Fracture Types

Posterior column and posterior wall fracture: It is the combination of the two described elementary fracture types. This fracture type is rare; the posterior wall fragment is mostly displaced cranially.

Transverse and posterior wall fracture: Transverse fracture is associated with posterior wall fracture. In most cases, the femoral head is dislocated posteriorly.

T-type fracture: This corresponds to a transverse fracture with an additional vertical fracture line crossing the obturator foramen.

Anterior column and posterior hemitransverse fracture: This fracture type, increasingly observed in elderly patients, is characterized by two separate lines – a concave cranio-caudally running fracture line of the anterior column and a transverse fracture line separating the posterior column at the level of the acetabulum.

Both columns fracture: All parts of the acetabulum are separated from the stable iliac segment. Usually, there are several fracture lines of the iliac wing. The acetabulum is completely unstable. No articular fragment stays connected to a stable proximal part of the innominate bone.

17.5.3 Diagnostics

17.5.3.1 Medical History and Clinical Examination

The injury mechanism (e.g., fall from a great height, dashboard injury) should raise suspicion to an acetabular fracture possible. Clinical examination shows painful restriction of motion of the hip joint, a resilient fixation of the leg, or a shortening or conspicuous rotational deformity of the leg. Precise neurological examination must be performed. Damage of the sciatic nerve is found in 10 % of cases, especially when the posterior column is involved.

17.5.3.2 Radiographic Diagnostic Procedure

Conventional X-Ray

Exact preoperative radiographic diagnostics are essential for classification and operative planning of acetabular fractures. To evaluate the localization and the extent of displacement of the fracture, standard X-ray in three projections and CT scan are required. Because the planes of the obturator foramen and of the iliac wing are located orthographically, the three following standard X-rays are recommended: a.p., ala, and obturator view (Fig. 17.18). The ala view, where the intact hemipelvis is lifted 45°, shows the iliac wing, the posterior column, and the anterior acetabular border. The obturator view, where the injured hemipelvis is lifted 45°, demonstrates the obturator foramen, the anterior column, and the posterior acetabular border.

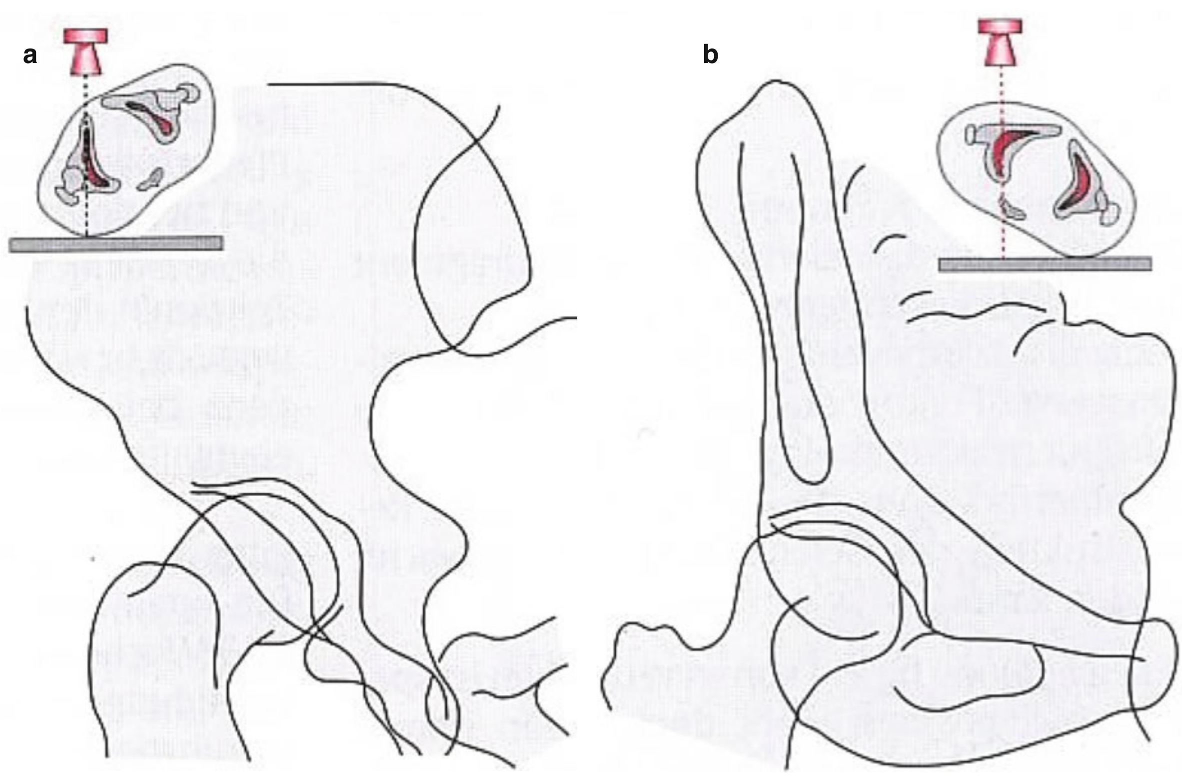

Fig. 17.18 X-ray techniques in acetabular fractures: (**a**) ala, (**b**) obturator view

There exist characteristic lines (landmarks) that may be helpful for classification. The iliopectineal line is the landmark for the anterior column, whereas the ilioischial line demonstrates the posterior column. By the lines of the anterior and posterior wall, fractures of the corresponding involved wall can be recognized. When the obturator foramen is involved, column fracture or T-fracture type must be assumed. Fracture lines crossing the iliac wing argue for an anterior column or a two-column fracture type. The spur sign caused by internal rotation of the caudal fracture fragments and the iliac bone attached to the sacroiliac joint can be regarded as pathognomonic for both columns fracture type. The acetabular roof has also to be identified.

CT Scan

Despite accurate standard X-rays, precise analysis of the acetabular fracture is often difficult. Therefore, CT scan must be performed, but the ala and obturator view should also be carried out to compare the intraoperative reduction of the fracture. Intraarticular fragments as well as impressions of the articular surface or of the femoral head can also be recognized by CT scan. By examining the axial view of the CT scan, column fractures are characterized by a transverse, transversal fractures by a vertical, and wall fractures by a typical angular course of the fracture. Three-dimensional reconstruction is a further helpful instrument for spatial association of the course of the fracture.

17.5.4 Treatment

17.5.4.1 General Aspects

The fracture type and factors related to the patient (e.g., age, concomitant injuries, and diseases) influence the indication as well as the surgical tactic.

17.5.4.2 Indication

The general condition of the patient (polytrauma, concomitant injuries, cardiorespiratory diseases) and the patient's age determine the management. The following factors concerning the type of injury influence the indication for a surgical procedure: instability of the femoral head and the congruency of the articular surface.

The "roof arc" of the superior articular surface according to Matta (Fig. 17.19) has been proven to assess the articular congruency. Using the three standard X-rays (a.p., ala, and obturator view) the angle between the perpendicular through the acetabular center and the first fracture line is measured. Surgical stabilization is recommended when this angle is less than 45° in one of the three standard projections. This "roof arc" can also be used for postoperative X-ray controls. Fracture gaps or displacement of more than 2 mm are

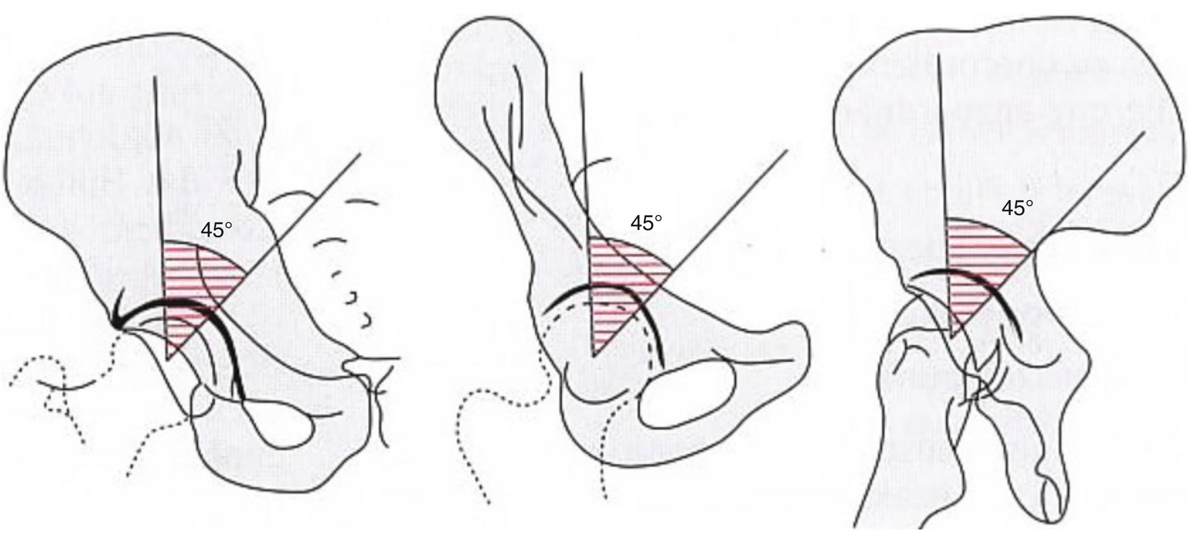

Fig. 17.19 Roof arc according to Matta

considered to increase the risk for the development of arthritis.

17.5.4.3 Nonoperative Treatment

The following fractures can be treated nonoperatively: undisplaced fractures; small, minor displaced posterior wall fragments; minor displaced anterior column fracture outside the roof arc; undisplaced low transverse fractures; comminuted fractures where anatomical reconstruction of the acetabular surface cannot be expected.

Treatment by traction is only recommended in posterior dislocations with impending risk of re-dislocation after closed reduction. Then, supracondylar traction using 1/7–1/10th of the body load is applied until definitive surgery performed as soon as possible thereafter. Lateral traction at the greater tuberosity is not recommended because of the risk of infection may compromising the approach.

Conservative treatment of acetabular fractures means starting of mobilization when analgesia is achieved. Partial weight bearing (15–20 kg) of the involved leg is necessary for 6–12 weeks, depending on the progression of fracture healing.

17.5.4.4 Operative Treatment

Because acetabular surgery is considered a highly demanding procedure requiring exact diagnosis and preoperative planning, the primary care is exceptional. Emergency indication is seen in open injuries, in anterior column fracture with laceration of the femoral vessels, and in posterior dislocation of the hip joint where closed reduction is not feasible. The best time for selective surgery is between the fifth and the eighth day after trauma. Surgery performed later than 2–3 weeks may be difficult due to already existing callus formation compromising the clinical outcome. In cases where both columns must be exposed (both columns fracture or transverse fracture), a two-step procedure can be performed at intervals of 3–5 days.

Operative Procedures

Operative procedure depends upon the fracture type, patient age, and the patient's general condition. In elderly patients, depending upon the fracture's surroundings, the bone stock, and concomitant diseases, a strained reconstructive procedure can be deliberately halted and primary or secondary endoprosthetic replacement of the hip joint can be performed.

Table 17.4 Acetabular approaches in relation to fracture type

Fracture type	Recommended Approach	Alternatively
Posterior wall	Kocher-Langenbeck	
Posterior column	Kocher-Langenbeck	
Anterior wall	Ilioinguinal	
Anterior column	Ilioinguinal	
Transverse	Kocher-Langenbeck	+ "trochanteric-flip" extended
Posterior column + post. Wall	Kocher-Langenbeck	
Transverse + post. wall	Kocher-Langenbeck	+ "trochanteric-flip"
T-type	Kocher-Langenbeck	Ilioinguinal
Anterior column + post. hemitr.	Ilioinguinal	
Both columns	Ilioinguinal	+ Kocher-Langenbeck extended

17.5.4.5 Approaches

Depending on the fracture type, two standard approaches have been established: the Kocher-Langenbeck approach and the ilioinguinal approach according to Letournel. In special fracture types and in delayed fractures. extended approaches can be performed (Table 17.4).

Kocher-Langenbeck Approach

This approach is performed with the patient in a lateral position. Using a traction table offers the advantage of dilating the hip joint, but includes the handicap of limited motion of the hip joint and the risk of traction-related damage of the sciatic nerve. Prone position is also feasible. Skin incision starts at the proximal lateral thigh crossing the greater tuberosity to dorsally (Fig. 17.20). The gluteus maximus muscle is dissected. The small external rotators (mm. piriformis, gemelli, obturatorius internus) are detached near the femur and retracted dorsally. Sciatic nerve and superior gluteal vessels have to be attended. The so-called "trochanteric-flip" osteotomy (Fig. 17.21) followed by a Z-shaped incision of the posterior capsule may be helpful to expose the anterior parts of the acetabulum.

The Kocher-Langenbeck approach is suited for exposure of the posterior column.

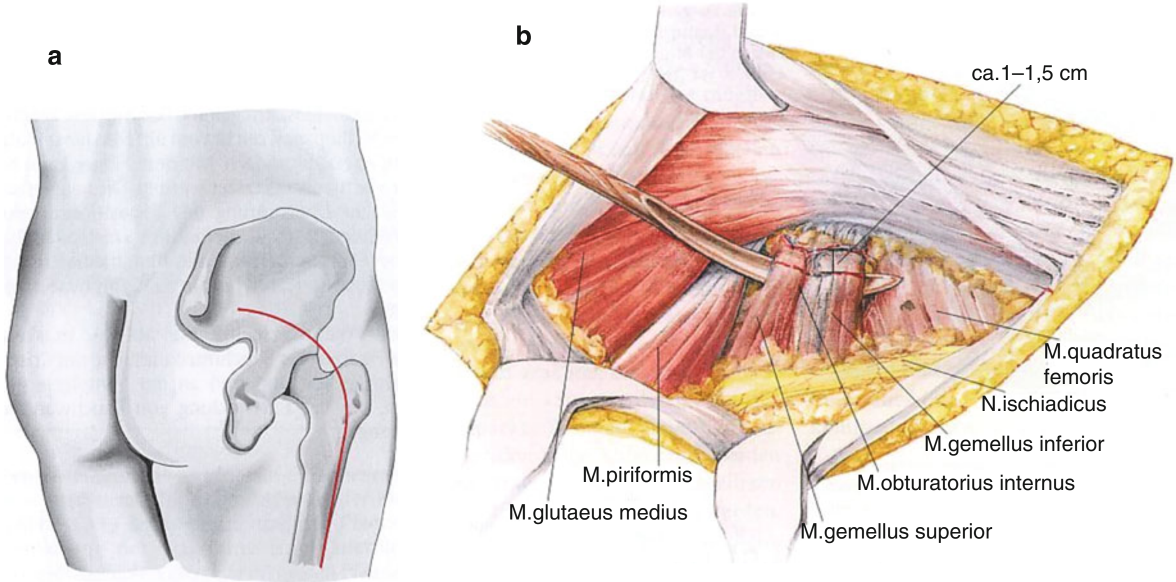

Fig. 17.20 Kocher-Langenbeck approach: (**a**) skin incision, (**b**) deep preparation

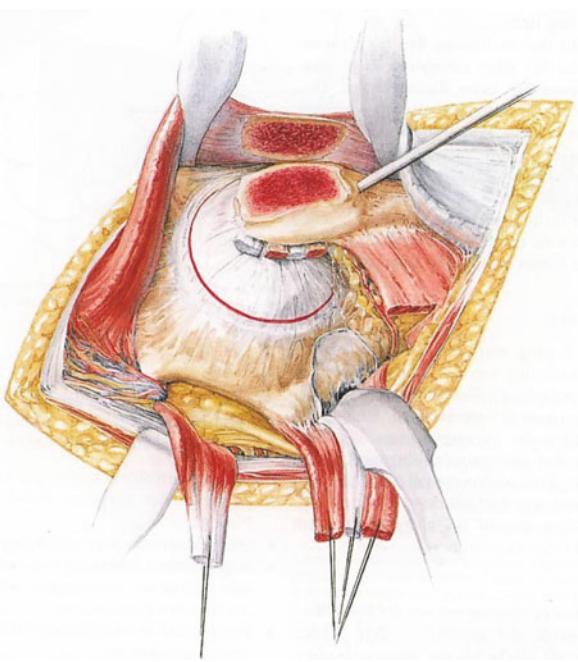

Fig. 17.21 "Trochanteric-flip" osteotomy

Ilioinguinal Approach

This approach is performed with the patient in supine position. Skin incision starts at the posterior iliac crest to the anterior superior iliac spine along the inguinal ligament (Fig. 17.22) External aponeurosis is dissected. The iliopsoas muscle is detached subperiostally. After dissection of the posterior wall of the inguinal canal, the psoas muscle together with the femoral nerve are looped, preserving the nervus cutaneus femoris lateralis. The femoral vessels as well as the spermatic cord or the ligamentum rotundum, respectively, are also looped in the same manner. To mobilize the femoral vessels, the arcus iliopectineus of the iliopectin fascia has to be dissected laterally of the vessels. The musculature of the iliac wing can be retracted using Hohmann retractors, K-wires, or Steinmann pins.

The first window, laterally to iliopsoas muscle, permits the exposure of the iliac wing and the sacroiliac joint. The second window, located between the psoas muscle and the femoral vessels, ranges from the anterior sacroiliac joint to the acetabular roof. The sciatic notch can be palpated by the finger to control reduction. The third window, medially of the inguinal canal, shows the superior pubic rim, the medial aspect of the acetabulum, and the symphysis.

During wound closure, exact reconstruction of the inguinal canal and refixation of the abdominal to the iliac crest and to the symphysis have to be attended to avoid developing of a hernia. The ilioinguinal approach is suited for exposure of the anterior column, of the acetabular roof, of the superior pubic rim, and of the symphysis.

Extended Approach

Extended approaches allow simultaneous exposure of both columns. But these approaches are tainted with

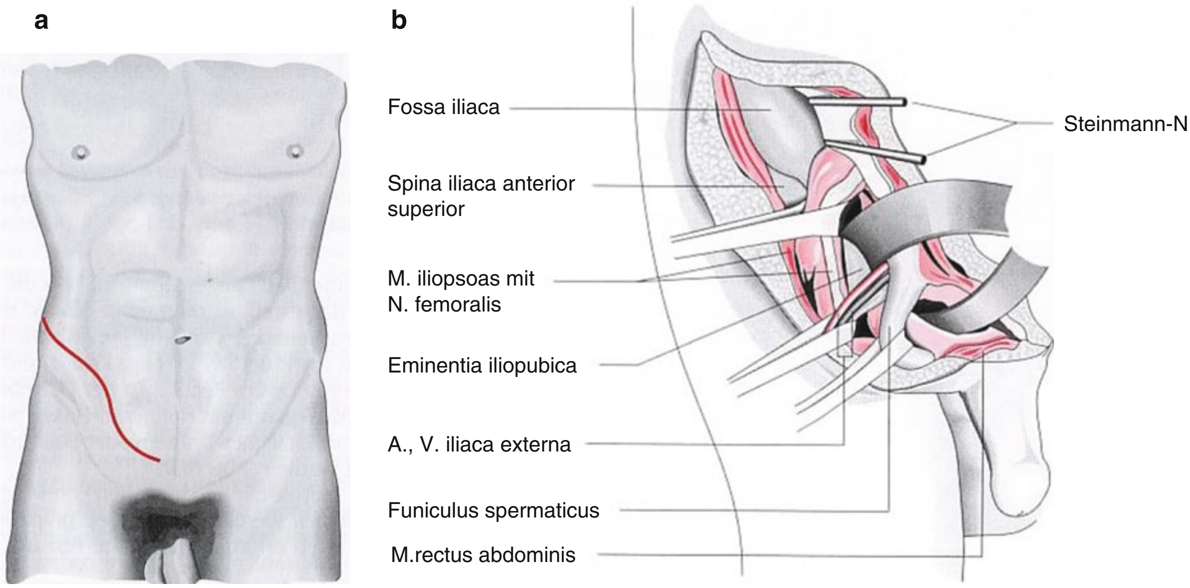

Fig. 17.22 Ilioinguinal approach: (**a**) skin incision, (**b**) deep preparation

the risk of complications of wound healing, and with increased incidence of heterotopic ossifications. The skin incision of the extended ilioinguinal or iliofemoral approach is carried out along the iliac crest to the anterior border of the tractus iliotibialis. Further subperiosteal preparation is performed medially or laterally of the iliac wing. Osteotomy of the greater femoral tuberosity is necessary. The Maryland modification is characterized by a T-shaped skin incision. Additional osteotomy of the anterior superior iliac spine is necessary. Reattachment of the sartorius muscle is required. Figure 17.23 gives a survey of the skin incisions of the extended approaches to the acetabulum.

Which Approach in Which Fracture Type?

The following fractures are exposed via the Kocher-Langenbeck approach: posterior wall fracture and posterior column fracture, and its combined fracture type.

The ilioinguinal approach is recommended in anterior wall fracture, anterior column fracture, and anterior column and posterior hemitransverse fracture.

Transverse fractures and transverse and posterior wall fractures are exposed via the Kocher-Langenbeck approach, if necessary, with additional "trochanteric-flip" osteotomy. In T-type fractures, the anterior or posterior approach is used, depending on the largest displacement. For both columns fractures, the ilioinguinal approach is usually performed. Additional Kocher-Langenbeck approach or extended approaches may be necessary.

17.5.4.6 Special Operative Technique

Operative Supports

There can be considerable forces required for reduction, which may be difficult to realize to the fragments.

A Schanz screw may be a helpful support. Inserted into the femoral neck, traction of the femoral head is feasible. When placed into the ischial tuberosity, derotation of the posterior column is enabled.

Special clamps (e.g., Matta, Jungbluth, Farabeuf), which can be fixed to tangential bore holes or to temporarily inserted screws, or the distractor can also be helpful supports. In cases of multiple fragments of the articular surface, K-wires can be used for stepwise reconstruction. The acetabulum should always be grouped by a curved clamp or by a rasparatorium to extract intraarticular particles.

The image intensifier using the a.p., ala, and obturator view is also indicated to control reduction and to confirm extraarticular position of the implants.

Implants

When the reduction of the acetabular fracture is accomplished, the fragments are fixed using lag screws. Normally, small-fragment, 3.5-mm cortical

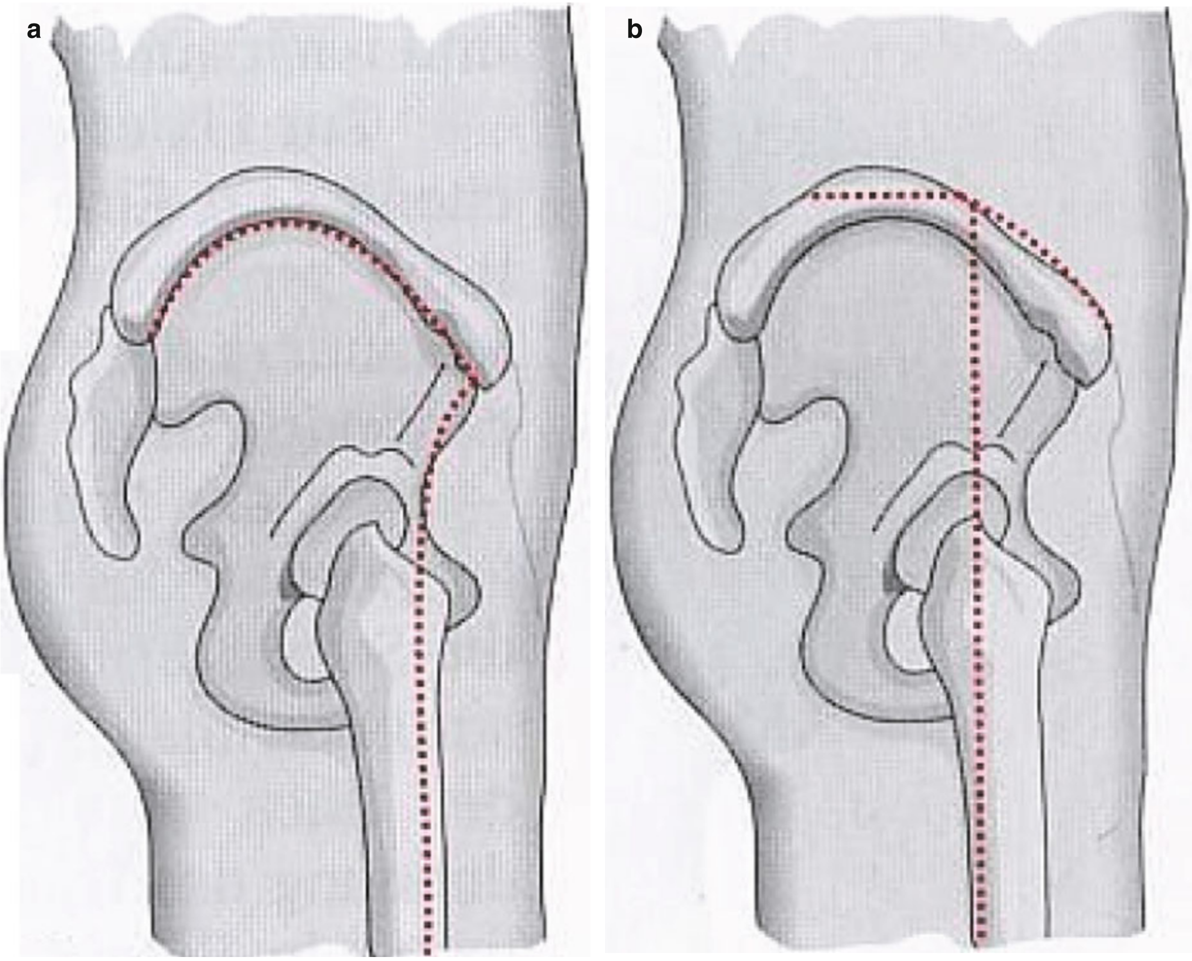

Fig. 17.23 Extended ilioinguinal approach (**a**), Maryland-modification (**b**)

screws suffice. Subsequently, the reductions clamps and further supports are removed to make way for additional plate fixation. Usually, 3.5-mm reconstruction plates are applied as standard implants.

Surgical Strategy

The operative principle consists of preferably anatomical reconstruction of the articular surface (i.e., gap or step <2 mm). If necessary, defects of the articular surface require cancellous bone graft. When reduction of the fracture is achieved, fixation is performed using lag screws and reconstruction plates. Solitary screw fixation has not been proven, especially in cases of posterior wall fractures, due to the risk of re-dislocation.

The screws have to be positioned within the safe area of the hip joint and must be controlled by axial image view.

Concerning the surgical management of the individual fracture types, the reader is referred to further literature. Posterior wall fracture, anterior column fracture, and the highly demanding transverse and T-type fractures are stabilized with lag screws and corresponding moulded reconstruction plates. Posterior column fracture is also fixed with a reconstruction plate. Lag screw to the anterior column increases stability. Transverse and posterior wall fractures usually require fixation with two plates (Fig. 17.24). Anterior column and posterior hemitransverse fracture is stabilized using a reconstruction plate along the linea terminalis. Lag screws above and below the acetabulum are used to fix the posterior column. Both columns fractures are operated on via an ilioinguinal approach using lag screws and a reconstruction plate. An additional Kocher-Langenbeck approach by a one-step or

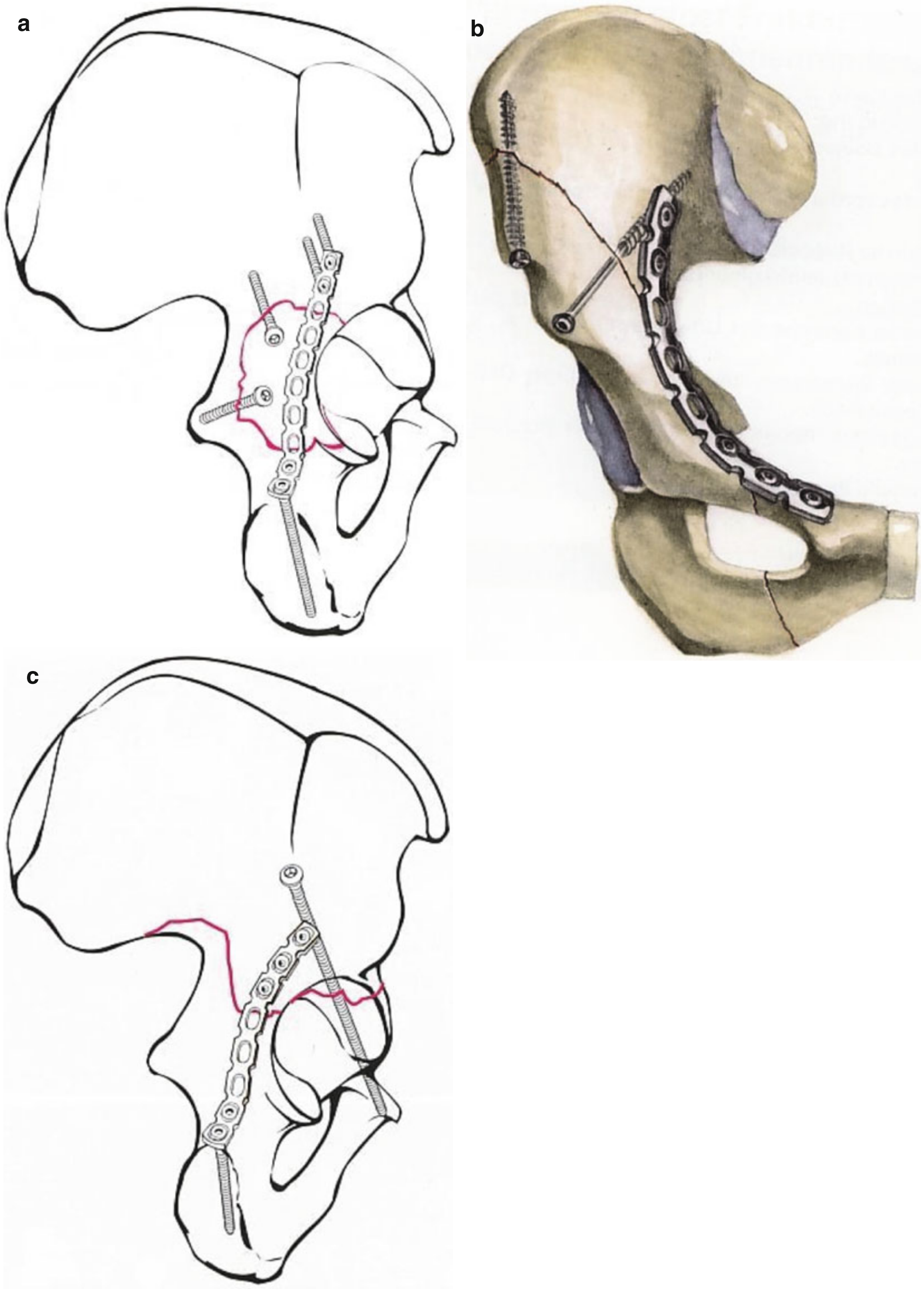

Fig. 17.24 Care of post. wall (**a**), ant. column (**b**), and transverse (**c**) fracture

two-step procedure may be required to control the posterior column.

17.5.4.7 Treatment of Pediatric Acetabular Fractures

Pediatric acetabular fractures are extremely rare (less than 0.01 % of all pediatric fractures). Extreme energy impact has to be assumed, which affects the epiphyseal plates converging in the acetabulum. These fractures are often not detected primarily. MRI may be helpful to identify the exact diagnosis.

In most cases, there is disruption of the Y-shaped epiphyseal plates. Even minor displaced fractures can result in a premature closure of the epiphyseal plates followed by subsequent reduced roofing of the femoral head.

Stabilization and reconstruction of the joint's congruency are achieved by screws and plates as it is seen with adults. Adapted implants (2.0 mm or 2.7 mm) are used in children younger than 10 years old, whereas standard implants are applied in adolescents. In solitary disruption of the epiphyseal plate, closed reduction and fixation with K-wires will usually suffice.

Partial weight bearing is recommended for 4–6 weeks. To avoid premature closure of the epiphyseal plates, removal of implants must be carried out 6–8 weeks after K-wire pinning was performed, and 5–6 months after plate fixation was achieved. In the first 3 years after trauma, regular (i.e., semi-annually) radiological controls should be performed to exclude premature closure of the epiphyseal plate. In the further course, special pelvic osteotomies or plastic reconstructions of the acetabulum may be required to reach a better roofing of the femoral head.

17.5.4.8 Acetabular Fractures in the Elderly

Well-reconstructable acetabular fractures in robust patients are stabilized in the above-described manner. The most frequent fracture types in the elderly are the both columns fracture and the anterior column and posterior hemitransverse fracture.

Minor displaced fractures and both columns fractures presenting a secondary congruency can be treated nonoperatively. Secondary endoprosthetic replacement of the hip joint may be necessary, in most cases due to acetabular protrusion requiring cancellous bone graft extracted of the femoral head. Primary endoprosthetic replacement may be indicated in challenging fractures. In doing so, preexisting arthritis, concomitant diseases, patient age, and compliance should be taken into consideration. But, in the majority of cases, internal fixation of the fracture is initially necessary to obtain an adequate bearing for the acetabular cup. The rotation center of the acetabular cup must be anchored into stable acetabular bone, otherwise, reconstruction of the acetabular fracture via an ilioinguinal approach is performed.

Secondary endoprosthetic replacement is feasible when fracture healing is completed.

17.5.5 Postoperative Treatment

In nonoperatively treated fractures mobilization, will start when pain relief is achieved. In cases where the fracture is treated by an internal fixation, partial weight bearing (10–15 kg) is started as soon as possible. Full weight bearing is allowed after 8–12 weeks, depending on radiological controls. X-ray controls (a.p., ala, obturator view) are taken postoperatively and after 6 and 12 weeks. To avoid periarticular ossification, medicamentous prophylaxis using indomethacin (2–3 × 50 mg) is recommended in cases where a posterior or extended approach was performed. The data for the period of this prophylaxis vary from 14 days to 3 months.

Removal of implants is usually not necessary; it may increase the risk of periarticular ossifications.

17.5.6 Complications

The lethality following acetabular reconstruction is about 0–3 % and it is increased in elderly patients (>60 years), mostly caused by pulmonary embolism following deep vein thrombosis.

Bleedings and neural lesions are counted among the *intraoperative complications*. Bleeding of the superior gluteal artery can result in extensive blood loss. In cases where the vascular stub is retracted through the sciatic notch inside the pelvis, surgical extension of the sciatic notch or a separate ilioinguinal or pararectal approach may be necessary to control the bleeding.

The femoral vessels can be damaged by incorrect drilling in the anterior-medial direction when the Kocher-Langenbeck approach is performed. Using an oscillating drill may help to avoid this complication. Extensive traction by hooks and hyperextension of the hip joint can cause development of deep vein thrombosis or damage of the femoral vessels. Therefore, flexion of the knee and hip joint is advisable.

The frequency of iatrogenic neural damage is reported to be about 5–17 %. Mostly, the sciatic nerve is involved by extensive traction by hooks when the posterior approach is performed. The use of special curved retractors and knee flexion may help to avoid this complication. In cases of uncontrolled hemostasis or bleeding resulting from the superior gluteal artery, the superior gluteal nerve can be damaged, yielding subsequent insufficiency of the gluteal musculature.

When the ilioinguinal approach is performed, the n. cutaneus femoris lateralis and the femoral nerve are jeopardized. The femoral nerve should always be leaved to the psoas muscle. Intraoperative flexion of the hip joint should also be obtained.

incidence of thrombosis of 10–20 %, postoperative infection, and postoperative bleeding are among the *early postoperative complications*. Infection rate is about 3–9 %. Early revision is required with consequent debridement and distinct lavages, so that implants can be leaved. Multiple revisions, local antiseptic irrigation, application of local antibiotics, and vacuum-sealing may be necessary. In cases of extensive soft tissue damage, a planned second-look procedure after 48–72 h should be performed.

Major postoperative bleeding mostly originates from the superior gluteal artery. Angiography may be helpful in recognizing the bleeding, with possible subsequent embolization. For surgical hemostasis, the sciatic notch must be expanded via the primary approach. Alternatively, a separate pararectal approach can be performed. When spontaneous hemostasis is feasible, extensive hematomas should be evacuated after 48–72 h.

When the postoperative X-rays present a poor radiological result, or when re-dislocation of the fracture becomes obvious, a CT scan should be performed to analyze whether the situation can be improved by a new surgical procedure. The implant fixed to one column often fuses the misalignment of the other column. Therefore, the whole assembly has to be removed and readapted.

Late postoperative complications include arthritis of the hip joint, necrosis of the femoral head, and periarticular heterotopic ossifications.

Depending on the fracture type, the incidence of arthritis is 7–22 %. It is mainly influenced by the exact reconstruction of the articular surface. Secondary endoprosthetic replacement may be indicated. Because these prostheses are tainted with an increased incidence of heterotopic ossifications, medicamentous prophylaxis using indomethacin is recommended.

The rate of necrosis of the femoral head is essentially dependent upon the intensity of the trauma, the duration of dislocation of the hip joint, and the patient's age. According to the extent and localization of the necrosis, revascularization procedures and adjusting osteotomies are rarely suitable. In the majority of cases, endoprosthetic replacement will be necessary.

Heterotopic ossifications are particularly found when the posterior approach is performed. Its incidence is increased after extended approaches and accounts for 10–40 %. Because it is also increased in secondary fracture care, early fracture care is the most important factor for prophylaxis. Surgical technique preventing soft tissue damage as well as adequate drainage of hematoma should also be guaranteed. Medicamentous prophylaxis using indomethacin is recommended for up to 3 months. Indication for surgery is seen when the range of motion of the hip joint is restricted (i.e., restricted extension, flexion <90°). The extent and the exact localization of the ossifications must be valued by a CT scan. Because of the high risk of recurrence, medicamentous prophylaxis and postoperative radiotherapy (7–8 Gy) are recommended.

17.5.7 Prognosis

The development of arthritis following acetabular fractures is dependent upon non-influenceable factors (such as patient's age, bone quality, primary damage of the cartilage) and upon the achieved articular congruency. The majority of necroses of the femoral head develop within the first 2 years. The rate of late arthritis is mainly dependent upon the reconstruction of the load-bearing cranial articular surface. Anatomical healing without signs of arthritis can be expected in about 70–80 % of cases, depending on the fracture type and on the surgeon's experience.

Table 17.5 Results of surgically treated isolated acetabular fractures (according to Letournel and Judet, to Matta, and to study group pelvis of AO)

Fracture type	Percentage of good and excellent functional results (Merle-d'Aubigné-score 15–18 pts)		
	Letournel and Judet (%)	Matta (%)	Study group pelvis (AO) (%)
Posterior wall	82	68	84
Posterior column	91	63	84
Anterior wall	78	67	50
Anterior column	88	83	92
Transverse	95	89	77
Posterior column + post. Wall	47	90	64
Transverse + post. wall	74	70	44
T-type	89	77	50
Anterior column + post. hemitr.	85	87	78
Both columns	82	77	88

The multicenter study of the AO and the German Trauma Society revealed no or mild pain in 65 % of patients suffering from a isolated acetabular fracture. Moderate and severe pain were observed in 35 % of cases.

The overall clinical result can be measured using the Merle-d'Aubigné score with the following parameters: pain, range of motion of the hip joint, and mobility.

Excellent or good overall clinical result can be assumed in 80–85 % after nonoperative treatment of undisplaced or minor displaced fractures.

The large series of Letournel and Judet analyzing 492 surgically treated acetabular fractures found excellent and good results in about 80–90 % of patients suffering from elementary basic fracture types (i.e., column, wall, and transverse fracture type). In transverse and posterior wall fracture types, the results were excellent and good in about 75 %, whereas in both columns fracture types in about 80 %. Poor prognosis, representing good results in only 47 % of cases, was seen in the posterior column and posterior wall fracture.

These results are confirmed by the study group (pelvis) of the AO and German Trauma Society. Thus, the worst results are obtained in anterior column fracture, in transverse and posterior wall fracture, in T-type fracture, and in posterior column and posterior wall fracture (Table 17.5).

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Pipkin Fractures

18

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18.1 Pathophysiology

During hip joint movement, 40 % of the surface of the femoral head articulates with the acetabulum and 10 % is in contact with the labrum. The areas of the femoral head that are not covered by the flat acetabulum are at risk of being shorn off at the acetabular rim while dislocating, thus provoking a femoral head calotte fracture (a Pipkin fracture). The damage to the bony structures of the joint is inversely proportional to the degree of flexion in the hip, meaning that less flexion results in greater damage. As a consequence, a fracture of the acetabulum and/or the femoral head with increasing fragment size will occur. If the hip is flexed more than 90 % during high impact, the incidence of a hip dislocation is almost mandatory. The most common cause of a hip dislocation and/or fracture of the femoral head is a dashboard injury, followed by a fall from a great height. The frequency of injury is five times higher on the right side than on the left side. Out of 100 patients with a hip dislocation, approximately five will suffer from a concomitant Pipkin fracture [2, 6, 7, 9].

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18.2 Clinical Findings

The clinical image of a hip dislocation is a shortened, interiorly or exteriorly rotated lower extremity with variable flexion in the knee joint. The most characteristic finding is that the affected leg is fixed in one position.

18.3 Diagnostics

18.3.1 Conventional X-Ray

A general a.p. overview image of the pelvis and an axial hip joint image of the affected hip are obligatory first steps. In many cases, the main features of the pathology can roughly be evaluated by these two X-rays. To complete the diagnosis and to detect further details, a CT scan must be performed. For follow-up examinations, conventional X-ray is adequate for detecting any changes.

18.3.2 Computed Tomography (CT)

CT is the gold standard imaging technique for diagnosing this pathology. Furthermore, it can detect an extension of the fracture into the femoral neck as well as other concomitant injuries. The optional reconstruction of a 3D image can enable an exact assessment of the size, allocation, and position of the shorn-off fragment of the femoral head. The CT is also used after closed reduction to determine relevant treatment options and to assess postoperative outcome.

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18.3.3 Magnetic Resonance Imaging (MRI, MRT)

MRI is irrelevant during the acute diagnosis, but it is predisposed for assessing long-term effects like osteoarthrosis or avascular femoral head necrosis.

18.4 Classification

The *Pipkin classification* [11] describes the following four types:

Type 1: Dislocation with fracture of the femoral head distal to the fovea capitis femoris

Type 2: Dislocation with fracture of the femoral head proximal to the fovea capitis femoris

Type 3: Type 1 or Type 2 injury associated with a fracture of the femoral neck

Type 4: Type 1 or Type 2 injury associated with a fracture of the acetabular rim

Type 4 was later expanded to include all kinds of concomitant acetabular fracture forms. The *Brumback classification* [3] is more comprehensive than the Pipkin classification:

Type	Description
1A	Dislocation with fracture distal to the fovea capitis femoris
1B	Dislocation with fracture distal to the fovea capitis femoris associated with an acetabular fracture
2A	Dislocation with fracture proximal to the fovea capitis femoris
2B	Dislocation with fracture proximal to the fovea capitis femoris associated with an acetabular fracture
3A	Dislocation with fracture distal to the fovea capitis femoris associated with a femoral neck fracture
3B	Dislocation with fracture proximal to the fovea capitis femoris associated with a femoral neck fracture
4A	Anterior dislocation with impaction of the femoral head
4B	Anterior dislocation with fracture proximal to the fovea capitis femoris
5	Central dislocation with fracture of the femoral head

The AO classification 31 C1, 2, 3 describes the shorn-off fragment, the impaction of the femoral head, the dislocation, as well as the concomitant femoral neck fracture (31 C3.3), but it does not consider a concomitant acetabular fracture [10].

18.5 Treatment and Complications

The most important step in the treatment of a dislocation is an early reduction of the hip joint within 6 h after the accident. If a closed reduction is not possible, an open reduction of the fracture, including all necessary operative steps, must be performed. After reduction of the joint, a control X-ray or, if possible, a CT scan of the fracture with an additional 3D reconstruction, must be performed.

The therapeutic algorithm and possible complications can be seen in the Table 18.1 [1, 4, 5, 8, 12–18].

Table 18.1

Type of fracture	Treatment method	Approach	Follow-up (*)	Complications
Pipkin 1/ Brumback 1A/ AO 31 C1.2	(a) Conservative (1)		Bed rest for 14 days followed by non-weight bearing for 6 weeks	Osteoarthrosis, AVN
	b) Operative (2): fragment excision,…, ORIF	1. Dorsal	Non-weight bearing for 6 weeks	Osteoarthrosis, AVN
		2. Ventral #	Non-weight bearing for 6 weeks	
Pipkin 2/ Brumback 2A/ AO C1.3	(a) Conservative (1)		Bed rest for 6 weeks followed by non-weight bearing for 6 weeks	Secondary dislocation, osteoarthrosis, AVN
	(b) Operative (2): ORIF, "The fragment attached to the lig. teres must not be disconnected"	1. Dorsal 2. Ventral #	Non-weight bearing for 12 weeks*	Secondary dislocation, resorption, osteoarthrosis, AVN
Pipkin 3/ Brumback 3B/ AO C3.2	Operative: biological age of the patient is decisive ORIF: early osteosynthesis (+) in younger patients "The femoral neck fracture has to be fixed prior to femoral head reduction!"	Postero-lateral approach is the rule, as an anterior dislocation in combination with these fractures is an exception	Non-weight bearing for 12 weeks*	High incidence of AVN
	Hip replacement in elderly patients (hemi- or total hip arthroplasty) (++)		Type of mobilization depends on the concomitant injuries, full-weight bearing is usually possible	Depends on the implantation technique
Pipkin 4/ Brumback 1B, 2B, 4B, 5/AO (?)	Operative: ORIF – management of the acetabular fracture and the fracture of the femoral head (+)	Depends on the type of acetabular fracture, usually dorsal approach	Non-weight bearing for 12 weeks	Early onset osteoarthrosis, AVN
	Hip replacement in elderly patients (total hip arthroplasty) (++)	Antero-lateral, or postero-lateral	Mobilization with partial- or full- weight bearing. Depends on the necessary implant to manage the acetabular fracture	Depends on the implantation technique

Conclusion

Corresponding to the notations in column 2 of the table, the following conclusions can be drawn:

(1) Conservative therapy is only indicated if the position of the femoral head fragment is anatomical after reduction and if the width of the injured hip joint capsule as seen on the general a.p. pelvis overview X-ray image is equal to the uninjured one.

(2) Operative treatment is indicated if there is an incongruity of the femoral head or the acetabulum, if the femoral head fracture is unstable, or in case of a femoral neck fracture.

(#) The anterior approach allows direct access to the so-called Pipkin fragment. Reduction and fragment fixation can be performed under direct vision. A dorsal approach for a posterior dislocation of the hip joint would increase the risk of additional vascular disruption to the femoral head.

(+) Age, possible secondary damage, compliance, cooperativeness, and general health status of the patient have to be taken into account before choosing osteosynthesis as the treatment option of choice.

(++) Depending on the biological age of the patient and the extent of the joint damage, the hemi- or total hip arthroplasty should be considered if a stable joint situation with the possibility of weight bearing can be guaranteed.

(*) The general aftercare policy routinely includes thrombosis prophylaxis, individual analgesics, and antibiotic treatment, as well as accompanying physiotherapy.

18.6 Illustrations

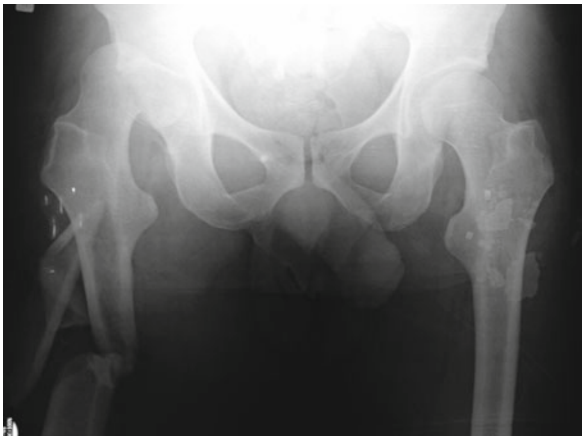

Fig. 18.1a Hip dislocation, Pipkin fracture, femoral shaft fracture

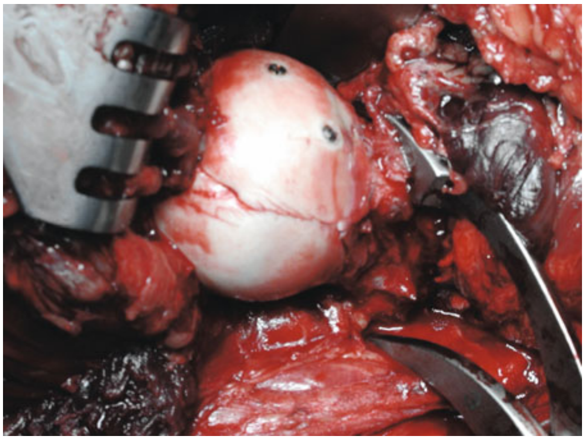

Fig. 18.1b Screw fixation of the Pipkin fragment

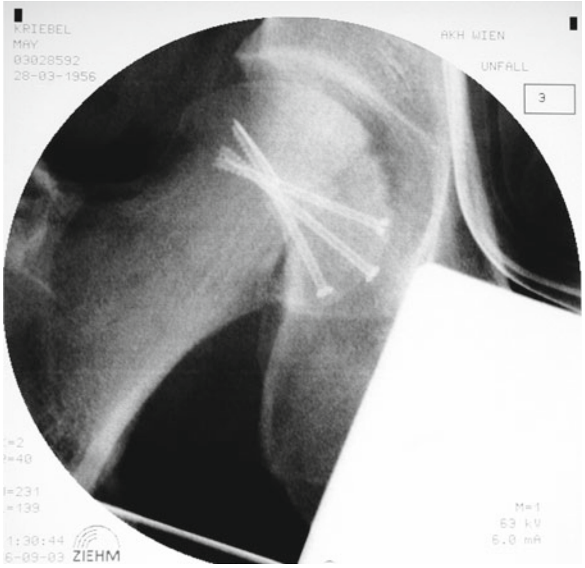

Fig. 18.1c Intraoperative control of the hip joint

Fig. 18.1d Intraoperative control after nailing of the femoral shaft

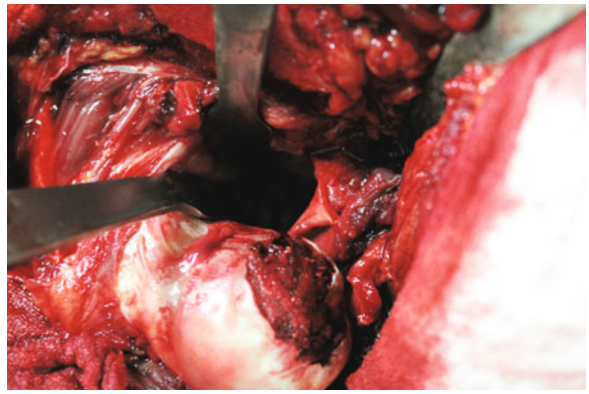

Fig. 18.2a Hip dislocation with shearing lesions of the femoral head

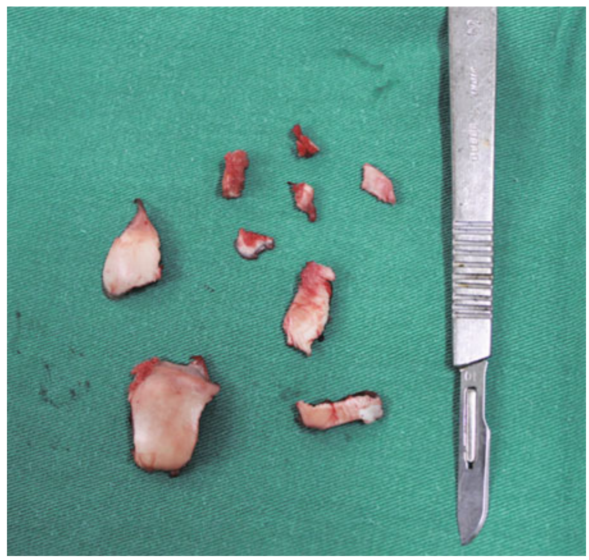

Fig. 18.2b Excision of multiple fragments

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Femoral Neck Fractures

19

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19.1 Anatomy

The femoral neck, which is situated between the femoral head and the trochanters of the thigh, is divided into three sections. The medial region is defined as the area between the femoral head and the field of maximal tapering. Adjacent is situated the lateral region of the femoral neck. The intersection to the trochanters is called the basocervical region, which is outside of the hip joint capsule. Therefore, a basocervical hip fracture is classified as a trochanteric fracture. Medial femoral neck fractures are intracapsular fractures, whereas lateral fractures occur around the insertion of the hip joint capsule. Furthermore, subcapital fractures run next to the border of the femoral head and are a subgroup of the medial femoral neck fractures [1, 2].

19.2 Etiology

A femoral neck fracture is usually either caused by high-energy trauma in young patients or by a simple fall in elderly patients due to a change in the mechanical quality of the bone. This change is usually caused by osteoporosis, osteopenia, limited mobility, clumsiness, and/or polymorbidity. A fracture occurs if the impact strikes directly at the mechanically weakened bone or if the load on the bone is potentiated because of a lacking or false defense mechanism. It can be preceded by a change in the hydroxyapatite crystal structure as well as by trabecular microfractures. Spontaneous and fatigue fractures can occur acutely or gradually. Of interest, more than 95 % of the fractures are caused by a direct fall onto the hip. Because this population age is increasing, the risk of postmenopausal fractures in women is rising too, with the result that women are affected four times more often than men at present.

Generally, osteoporosis is evident after the occurrence of a femoral neck fracture. Therefore, a comprehensive evaluation and an adequate treatment are crucial [1, 8]. It will take at least 2 years for patients to recover the same or similar life expectancy as their uninjured contemporaries. Mortality caused by femoral neck fractures is estimated to be approximately 5 % during the initial inpatient treatment; it increases to 30 % in the first year.

19.3 Pathophysiology

The blood supply of the femoral head is primarily guaranteed during growth by two sources. The femoral epiphysis is fed by the vessels that run through the ligamentum capitis femoris into the epiphysis, or it is drained venously. The femoral neck itself is fed by the branches of the arteria circumflexa femoris medialis and lateralis, which enter the bone at the basis of the femoral neck around the origin of the capsule and then form a racemose network in the bone. Veins and venula that run parallel to the arteries and arteriola ensure the backflow of the blood. After the epiphyseal plate has closed, the blood flow of a. and v. ligamenti capitis femoris constantly decreases, resulting in a reduced activity of 10 % at most, whereas the importance of the metaphyseal blood supply constantly increases.

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19.3.1 Cause of Blood Supply Dysfunction of the Femoral Head After a Femoral Neck Fracture

The factors that cause blood supply dysfunction are

- Increase of the local tissue pressure (edema) exceeding the capillary pressure that induces compression of the vessels, especially of the veins [4]; reduction of the intraosseous perfusion pressure
- Increase of capillary permeability
- Tissue hypoxia

In case of a fracture, the fragment displacement can either partially or completely damage the sustained vessels, for example, causing rupture or thrombosis. Furthermore, the concomitant intracapsular hematoma may compress the vessels and therefore cause dysfunction. Additionally, an intraosseous hematoma that develops in the fracture site may be the reason for obliteration. All of the mechanisms mentioned above are influenced by the degree and frequency of movement between femoral head and neck, resulting in an increase of the damage.

19.4 Clinical Findings

Typical clinical findings can only be observed in complete fractures in which the surfaces between femoral head and neck are noticeably dislocated. These are

- Shortening of the leg
- Exteriorly rotated leg
- Inability to lift the leg from the surface (the load to the leg is extremely painful and impossible to lift)

If only one of these symptoms appears, the existence of a femoral neck fracture has to be assumed, using all possible diagnostic tools, until the contrary has been proven. Concomitant sensory or motor sensory nerve injuries can also arise, as well as peripheral circulation problems caused by an accompanying injury or already evident prior to the injury.

19.5 Diagnostics

19.5.1 Conventional X-Ray Diagnostics

A general a.p. view of the pelvis and an axial view of the hip joint enable a correct diagnosis in 95 % of all cases if the quality of the x-rays is good and in focus. Obesity and/or lack of cooperation can reduce the quality of the image significantly.

19.5.2 Computed Tomography (CT)

A coronary and sagittal cross-section are needed in order to verify fractures (Fig. 19.1) that are not detectable on conventional X-rays (3–4 %)

19.5.3 Magnetic Resonance Imaging (MRI, MRT)

MRI is rarely indicated, generally only if a fracture cannot be detected using CT scan (1–2 %). Undoubtedly, the MRI is not a first-line diagnostic tool. If it is performed earlier than 5–6 h after the accident, it can be falsely interpreted as negative.

Other diagnostic methods such as conventional X-ray tomography, scintigraphy, and ultrasound examination are obsolete. They do not play a role in routine diagnostics and are not used. About 1 % of all femoral neck fractures are not detectable at all; they manifest after days or weeks with the classical clinical image.

19.6 Classifications [6, 7]

19.6.1 Garden Classification (Fig. 19.2)

This classification is based on the degree of the displacement of the fracture fragments in a.p. and axial X-rays [6, 7].

Garden I: “incomplete,” valgus impacted fracture, the femoral head is attached in valgus like a mushroom cap on the femoral neck. A fracture is considered as compressed if the a.p. X-ray shows a valgus displacement of the femoral head without any axis deviation in the axial plane. If the axial X-ray reveals an antecurvatum (more often) or a retrocurvatum (less often) and if the fracture gapes, it is still reasonable to categorize it as an incomplete fracture. An exact interpretation of the x-rays is crucial for the adequate choice of treatment. Conservative therapy can only be applied for fractures with compression on both planes.

Garden II: “complete” fracture of the femoral neck. It is detectable on the X-rays in two planes, without any axis deviation in the two planes.

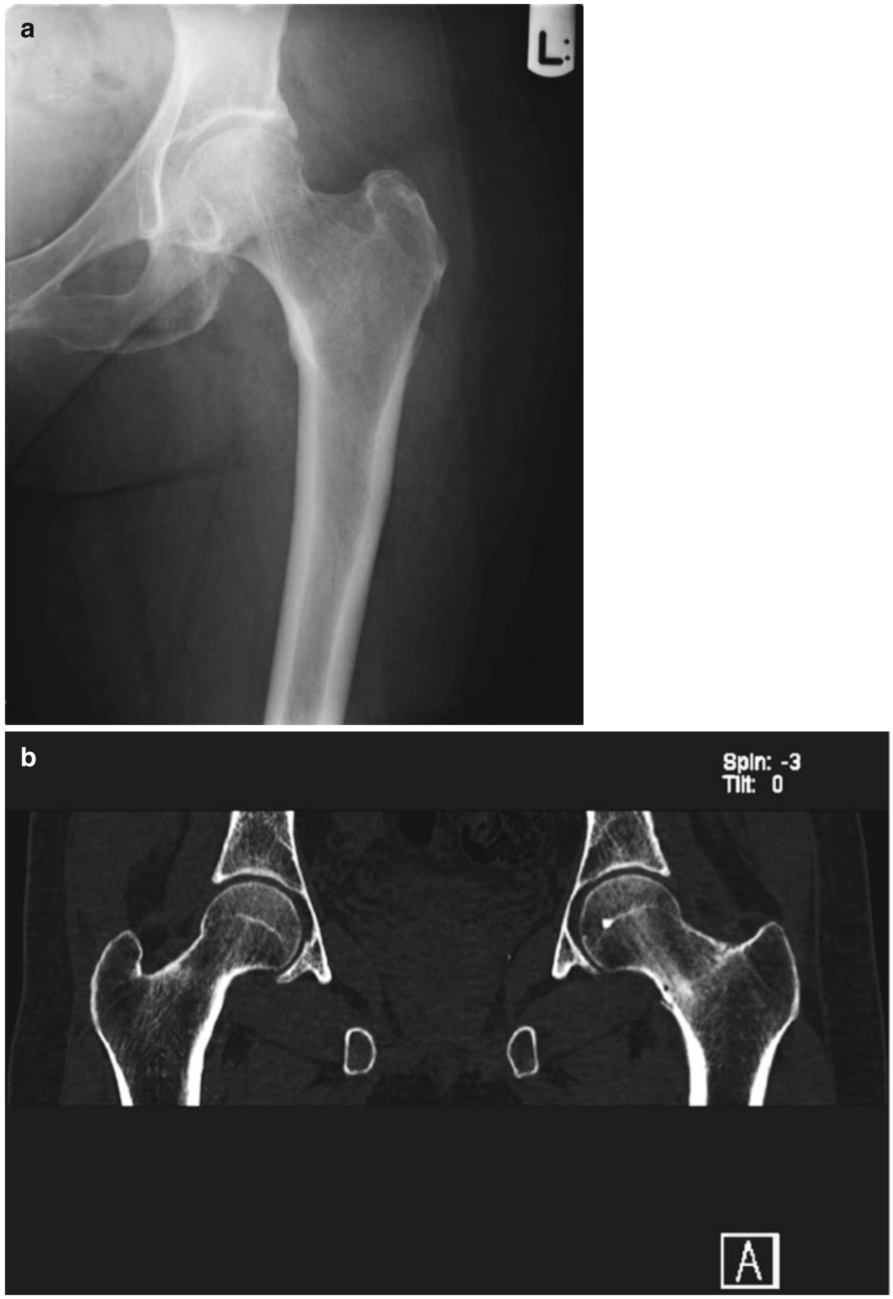


Fig. 19.1 (**a**, **b**) Suspected femoral neck fracture X ray (**a**), CT (**b**)

Garden III: partially displaced fracture. The femoral head and neck are misaligned, the axis proportions have changed, but both fragments are still in contact. Therefore, a reduction using simple procedures seems to be possible.

Garden IV: completely displaced fracture. Fracture surfaces of the femoral head and neck are completely dislocated. Reduction is hardly possible or can only be achieved with great difficulty.

The Garden classification reflects the probability of vascular damage resulting from the fracture type. It could be an indicator of avascular necrosis of the femoral head, a long-term consequence of the femoral neck fracture because the degree of the displacement correlates with the degree of blood supply dysfunction of the femoral head. As a consequence, the probability of the development of an avascular necrosis is low in a Garden I fracture and high in a Garden IV fracture.

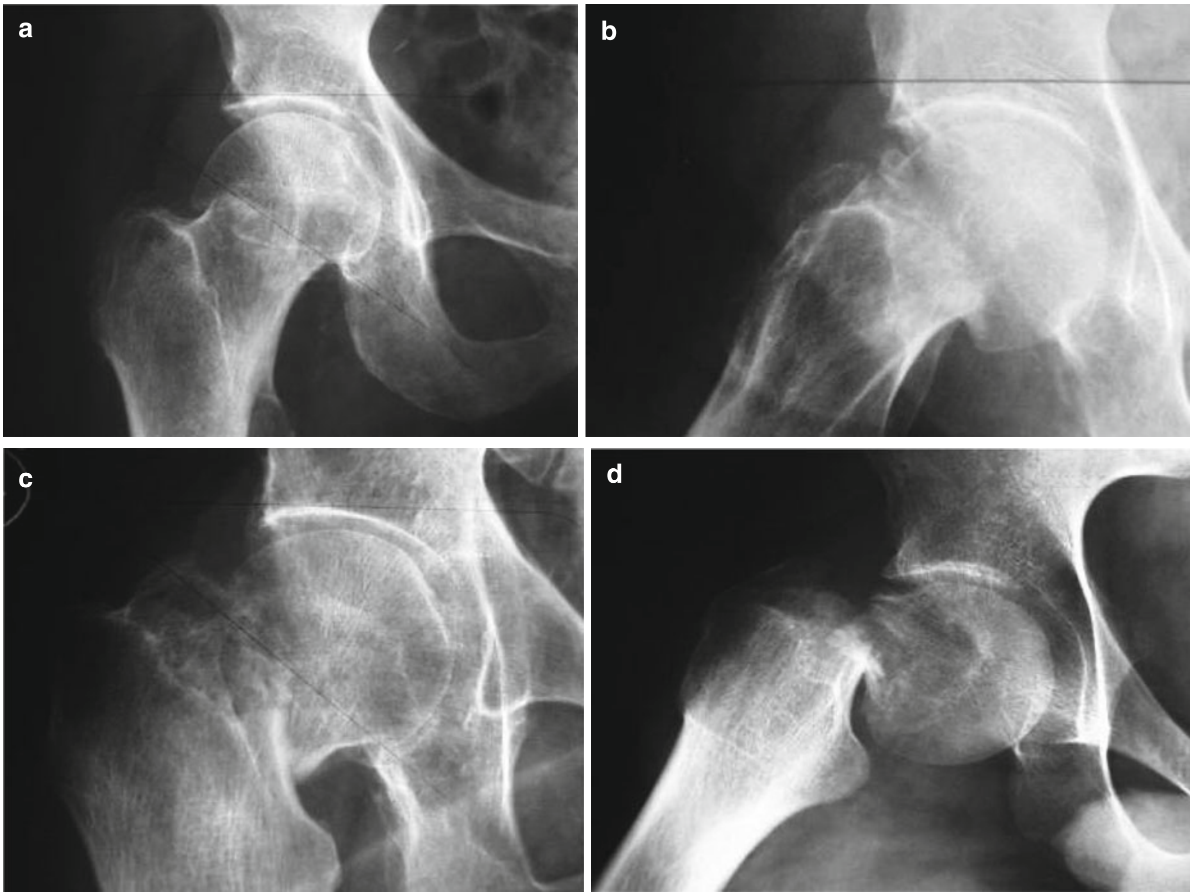


Fig. 19.2 Garden classification [6]: (a) In valgus impacted. (b) Undisplaced. (c) Displaced, fracture surfaces are partial in contact. (d) Displaced, fracture surfaces have lost their contact

Because there is no linear relationship between displacement and blood supply dysfunction, the *Garden alignment index* was introduced. For its calculation, the angles between the trajectory course in the femoral head and those axis that are generally used to describe the hip joint (CCD) have to be measured. The likelihood of the development of a femoral head necrosis is directly proportional to the magnitude of the angle in a.p. view and to the deviation of the angle from the straight line in the axial view. If this deviation exceeds 20–30°, the incidence of a femoral head necrosis has to be assumed.

19.6.2 Pauwels Classification

This classification describes the mechanical stability of femoral neck fractures with the aim of predicting the probability of the development of a pseudarthrosis (nonunion) or of a femoral head necrosis. The basic principle of this assessment is the *Pauwels angle,* which is formed between an imaginary horizontal line drawn through the acetabular roofs, for example, and the line drawn through the fracture planes. The magnitude of this angle is inversely proportional to the stability of the fracture. The incidence of nonunion and probably of avascular necrosis of the femoral head is low in pointed angles, whereas the possibility of both complications increases with the magnitude of the angle [11].

Pauwels I: The Pauwels angle is 30°.
Pauwels II: The Pauwels angle is 50°.
Pauwels III: The Pauwels angle is 70°.

The Pauwels angle can only be determined reliably from optimal a.p. images. The first X-rays usually cannot be made, because of immense pain, in the correct

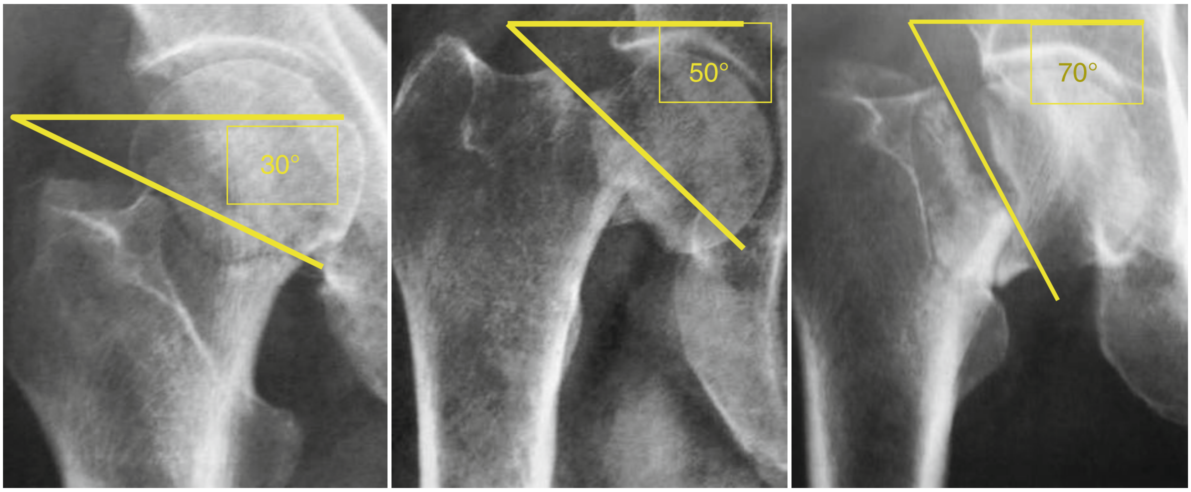


Fig. 19.3 Pauwels classification [11]: (I) The angle between a horizontal line and the fracture line is around 30°. (II) The angle between a horizontal line and the fracture line is around 50°. (III) The angle between a horizontal line and the fracture line is around 70°

a.p. position of the pelvis and of the affected leg; the accurate evaluation of the angle is impossible and therefore unreliable. To be able to determine the treatment of choice, the X-rays must be carried out under completely pain-free circumstances. As a consequence, this classification cannot be considered as an indispensible decision-making aid (Fig. 19.3).

19.7 Treatment of Femoral Neck Fractures

19.7.1 Conservative Treatment

19.7.1.1 Indication

Conservative treatment is only indicated in Garden I fractures or in all other fracture forms, if the patient's general health status does not allow surgical or anesthesiological intervention.

19.7.1.2 Complications

Conservative treatment is connected to all the risks and dangers of long-term bed rest: development of decubiti (sacral, back, and heel), urinary tract infection, pneumonia, pulmonary and cardiac insufficiency, thrombosis and pulmonary embolism. Preventive measures like infection prophylaxis, breathing therapy, and physiotherapy in bed should be prescribed in order to impede the development of thrombosis, decubitus, and infection.

19.7.2 Femoral Head–Preserving Treatment Methods

19.7.2.1 Indication

There is an absolute indication to treat femoral neck fractures surgically. In younger patients (with a biological age between 60 and 65 years), a higher degree of displacement of the fracture fragments is tolerated for head-preserving osteosynthesis. If the femoral head remains vital and heals in a correct position, the patient will have long-term benefits with no further need of any intervention. If not, a corrective surgery using a total hip prosthesis can be performed later on without endangering the patient with good general health status. The usage of a primary total hip arthroplasty in young patients most likely provokes further surgeries with increasing risk of associated complications.

19.7.2.2 Timing of Surgery

The osteosynthesis has to be performed as early as possible after the accident. Surgery performed within 6 h combined with secure stabilization of the femoral neck fracture enables an optimal initial situation resulting in the best achievable outcome.

19.7.2.3 Anesthesia

There are three methods of anesthesia to choose from:

- General anesthesia with orotracheal intubation, or larynx mask
- Epidural anesthesia or spinal anesthesia
- Nerve block anesthesia or local anesthesia

The method of choice depends on the patient's general state of health, comorbidities, patient positioning during surgery, and length of surgery, as well as on the anesthesiologist's preference.

19.7.2.4 Operative Techniques

The primary aim of the surgery is an anatomical reduction, which can either be achieved by exposing the fracture through an anterolateral approach to the hip joint (open reduction technique) or by positioning the patient on a traction table with manipulation on the affected leg (closed reduction). A valgus position (hat on the hook) of the femoral head is not desirable for the following reasons:

- An overcorrection of the alignment index according to Garden has an adverse effect and corresponds with a bad result, comparable to avascular necrosis of the femoral head.
- An intact joint capsule in combination with valgus position of the femoral head can cause obliteration or pinching of the vessels that run cranially on the corticalis or in the joint capsule.

In general, the advantages and disadvantages of the closed method are at equilibrium. However, the closed method is less stressful for the patient and it probably shortens the length of the surgery. Requirements for the usage of the closed method are the availability of a traction table and at least one image intensifier; two image intensifiers facilitate reduction control significantly.

Because of repetitive burden, direct and indirect radiation exposure to the surgical team should be measured by digital dosimeters. The single exposure of a patient can be disregarded because it is small; additionally, all parts of the body lying outside the operation area are protected by lead covers.

After appropriately analyzing the fracture, an accurate assembly of the traction table is crucial because excessive traction might damage the n. ischiadicus and especially the n. peroneus. In rare cases, an anatomical reduction cannot be achieved using the closed method, therefore causing the need to proceed to an open version. Tolerating an incomplete or insufficient reduction is a mistake.

Screws

After anatomical reduction of the fracture, three to four cancellous bone screws are applied parallel through laterally placed stab incisions on the skin. In the case of using four screws, each of them is placed in the middle of the four quadrants; in the case of using only

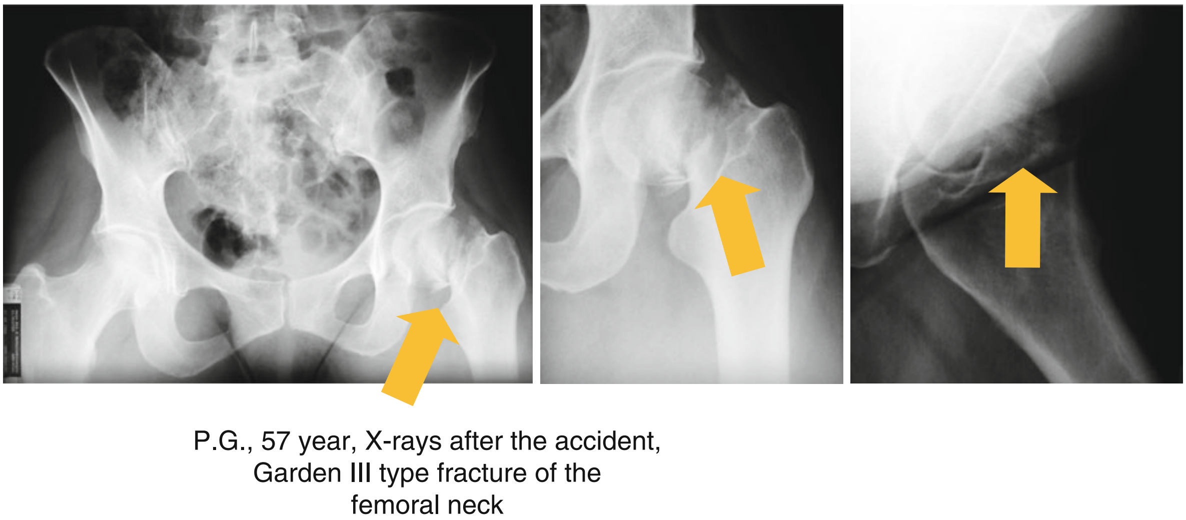
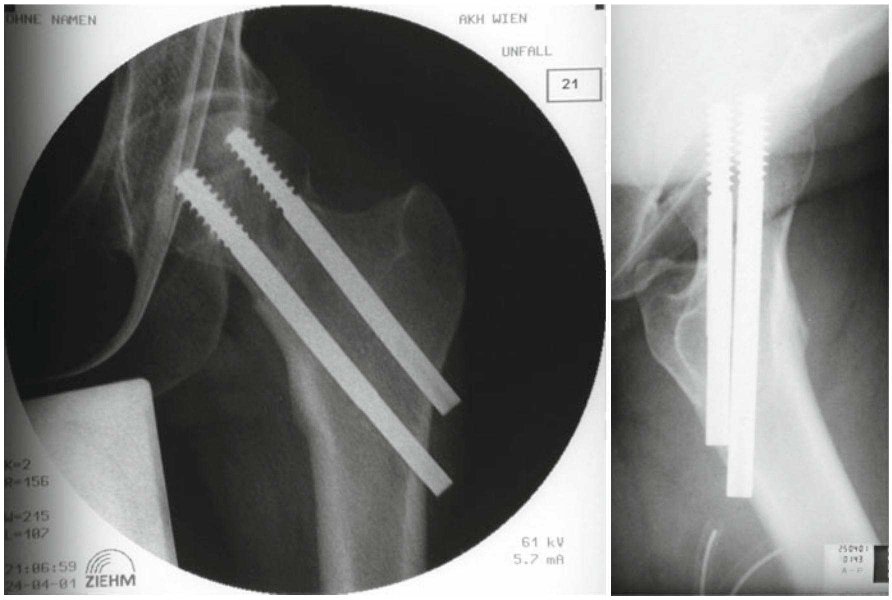
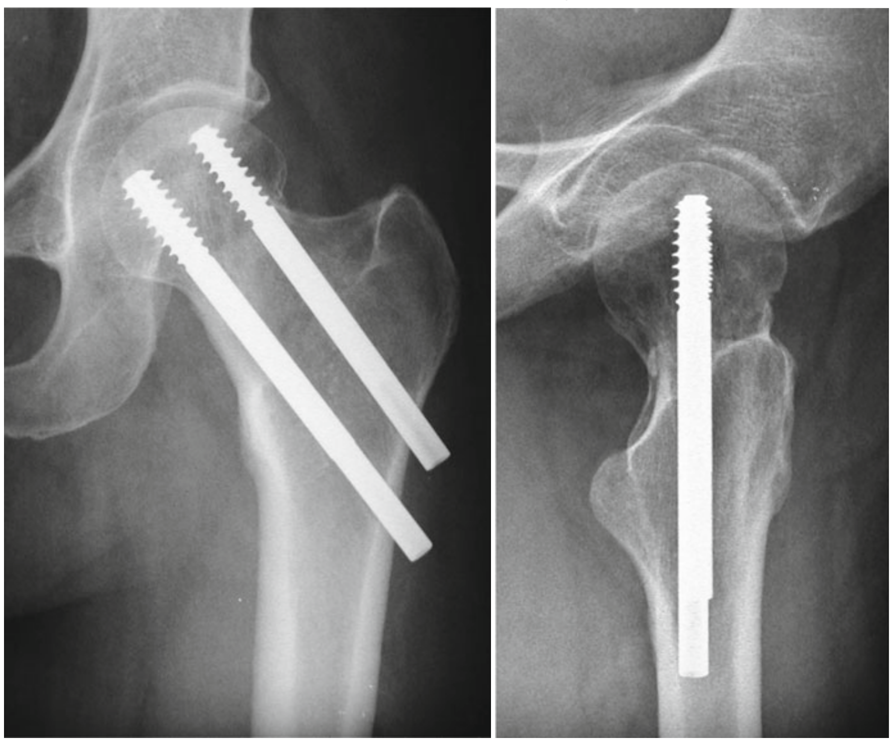


Fig. 19.4 Femoral neck fracture – Type Garden III – Head saving procedure with two cannulated screws. (1) X-rays after the accident. (2) X-rays postoperative 6 h later. (3) X-rays 4 months later. The fracture is consolidated

Fig. 19.4 (continued)



P.G., 57 year, p. op.



P.G., 57 year, 4 months later

three screws, they are positioned like an upright triangle, with two screws in the middle of the two caudal quadrants. The position of the screws must be parallel to the femoral neck axis at an angle of approximately 130° to the femoral shaft axis according to the CCD angle. To achieve an optimal position of the implants, cannulated screws are preferred. With their use, it is easier to position the guide wires and, if necessary, to change their position without any damage. Furthermore, target devices for proper placement are available.

Classical cancellous bone screws have a core diameter of 4.5 mm and an external one of 6.5 mm; the length of the screw thread used is 15 mm or 30 mm.

The screws must be inserted in a way that their thread is only located in the head fragment, allowing the lateral part of the screw to glide in the trochanteric region. In consequence, repetitive compression force on the head will not be hindered and a fracture gap between the fragments can be prevented. For better anchorage of the screw in the bone, the tips should be placed as close as possible to the subchondral surface of the head (2–3 mm distance). In order to achieve sufficient compression of the fracture areas, washers should be used in combination with conventional spongiosa screws. Compression forces on the fracture side provoke a shortening of the femoral neck length resulting in a protrusion of the screws over the lateral corticalis, which can be seen on the X-ray after several weeks or months.

In addition to the classical spongiosa screws, special femoral neck screws for treating femoral neck fractures are offered by several manufacturers (Fig. 19.4). These special cannulated shaft screws with an exterior diameter of 7.5–9.5 mm do not have a head. Their thread length is less than 20 mm. Little holes are situated in the pitch of screw thread to enable drainage of the intraosseous hematoma or edema. The cannula and holes are furthermore designed for inserting hookpins, which can be driven into the spongiosa at the tip of the screw. This can clearly enhance the stability of the screw anchorage.

With screws of larger diameter (8.5 mm and 9.5 mm), two screws are generally used to stabilize the fracture. The cranial screw should be inserted as high as possible in the a.p. view. In the axial view, it should be placed slightly anterior to the middle of the femoral neck. The caudal screw should be positioned as low as possible, close to the Adam's arch in the a.p. view and posterior to the middle of the femoral neck in the axial view. The correct position of the two screws should prevent their diagonal displacement, which can be caused by rotation of the head fragment. Many of these screw systems can be complemented with a one-hole side plate. Connecting of the peripheral screw end with the plate should counteract a secondary varus displacement of the head fragment.

The Dynamic Hip Screw [16, 17]

After reduction of the femoral neck fracture, the axis of the femoral neck has to be elongated virtually to the skin level of the lateral side of the thigh, indicating the correct starting point for an incision of 10–15 cm length. After splitting of the fascia, the origin of the vastus lateralis on the septum intermusculare is dissected from posterior to anterior and perforating vessels of the septum are ligated. With the help of the target device, a 2-mm guide wire with a threaded end is drilled from the lateral corticalis into the anatomical middle of the femoral head until the tip lies in a subchondral position. Afterwards, length measurement has to be made to evaluate the intraosseus distance from the lateral corticalis to the surface of the femoral head, keeping in mind that a 5–10 mm gap between the tip of the screw and the surface of the head should be preserved. In the case of less distance to the surface, cracks of the cartilage can occur, causing an intraarticular bleeding. If the screw tip is further away than 10 mm, the anchorage in the femoral head fragment could be too short and therefore too weak, eventually resulting in a lateral slipping of the screw. After choosing the adequate screw length, the triple reamer is set to the length of the implant selected.

After the triple reamer, the tap is used. According to better bone quality, the risk of an unintended rotation of the head fragment increases, resulting in a destruction of all remaining connections between the head and the neck fragment. To avoid this mischance, a second guide wire can be inserted parallel to the first one in a way that there is enough space between them to not impair further operative procedures. As a next step, the head screw has to be implanted in a way that the screw thread is solely situated in the head fragment. Then the usually used two-hole DHS plate is slid onto the screw until it has full contact with the lateral corticalis. Finally, the plate is fixed with the designated number of corticalis screws. The head screw can now be pulled into the sleeve until the desired compression between the fracture fragments is achieved, aiming to counteract a secondary contortion of the head fragment in the course of time. Because this compression screw will loosen during healing, it should be removed immediately after completion of this step. Subsequently, cyclic load should enhance further compression. Wound closure has to be performed according to the generally valid guidelines. Postoperatively, X-rays in two planes should be performed to verify the correct placement.

Table 19.1 Treatment algorithm – femoral neck fracture (FNF)

FNF	Garden I, Garden II	Garden III, Garden IV
Diagnosis	X-ray, CT, MRI	X-ray
Conservative therapy	Garden I + bad general condition	Bad general condition
Head saving procedure	Yes	Age dependent
Time of surgery	Acute!	Acute!
Open reduction	Exceptional, not needed as a rule	Exceptional, not needed as a rule
Closed reduction + fracture table	As a rule	As a rule
Intracapsular hematoma	Evacuation age dependent	Evacuation age dependent
Hemi-arthroplasty (HHP)	No	Age dependent
Total arthroplasty (HTAP, HTEP)	Exceptional	Age dependent
Ambulation – weight bearing	From case to case	From case to case

19.7.2.5 Special Aspects of Garden Fractures [12, 13]

In case of correct radiologic diagnosis of the impaction (see Classification), Garden I fractures detach between 41 and 52 % of the time, resulting in a dramatic impairment of the prognosis with regard to the vitality of the femoral head. As a consequence, head-preserving osteosynthesis is counterproductive. A secondary displacement is observed in 10 % of the patients under the age of 70 years and in 42 % of the patients over 70 years. Therefore, in order to improve the results, these fractures must be treated surgically as early as possible. Postoperative mobilization should be carried out according to the usual criteria. Of course, patients who are classified as inoperable have to be considered as an exception (Table 19.1).

19.7.2.6 Postoperative Treatment

Postoperative treatment consists of wound care, thrombosis prophylaxis, mobilization, and X-ray control.

Younger patients can normally be mobilized with toe-touch weight bearing (10–15 kg load). The reason for this regimen without complete non-weight bearing is the possible negative effect on the healing process caused by distraction of the fracture surfaces as a result of a freely suspended leg.

X-Ray Control

This has to be performed in two planes after mobilization (2–5 days postoperatively), after 14 days, and then every 4 weeks until osseous healing of the fracture is evident. Afterwards, follow-up X-rays are only indicated in the case of apparent or increasing discomfort.

19.7.2.7 Complications

Wound Hematoma

In very rare cases, wound hematomas are pronounced enough to necessitate revision. If the surgical wound is tense, if excessive bloody drainage is observed, or if blood loss is detected compared to the postoperative lab control, a wound revision has to be performed, being aware of the clotting status. All wound layers have to be opened and irrigated, thoroughly searching for the source of bleeding. A tissue or swab sample for bacterial-microbiological examination is necessary. After drainage of each layer and wound closure, consecutive monitoring is obligatory. Furthermore, antibiotic prophylaxis is recommended.

Infection and Prevention

Of femoral neck fractures, wound infections are rare after head preserving surgery (0.5–1 % according to standard opinion).

The existence of a hip joint empyema always must be considered (especially when cannulated screws were used, because the guide wire could have perforated the femoral head). Appropriate diagnostic steps are needed to rule out this serious complication. If this is not possible, osteosynthesis has to be removed and the femoral head has to be extracted. According to the given circumstances, a one- or two-stage hip joint replacement must be performed, preferring the two-stage version if uncertainties remain.

The Avascular Necrosis of the Femoral Head

This occurs as a result of the interruption of the arterial blood supply and/or obstruction, or occlusion of the venous drainage of the femoral head caused by a femoral neck fracture. The revitalization process was insufficient or absent.

The femoral head necrosis can be partial or total. Sugano and colleagues [15] divide the types of necrosis into three groups:

Type A affects a necrosis area less than one-third of the weight-bearing area of the femoral head, which is defined as the zone limited by the connection line, lying between the acetabular edge and the Köhler's teardrop figure.

In *Type B,* the necrosis area covers more than one-third but less than two-thirds of the weight-bearing area.

Type C is divided into C1 and C2. C1 includes cases in which the changes cover more than two-thirds of the weight-bearing area, without reaching the acetabular edge. In C2, the necrosis area overlaps the projection of the acetabular edge on the femoral head.

The frequency of avascular necrosis of the femoral head and the time period between the accident and the surgery seem to be related. Fekete et al. [5] reported that, out of 2,275 femoral neck fractures (Garden I to IV), a head necrosis rate of 12.3 % was evaluated if the surgery was performed in the first 6 h after the accident and 19.8 % if it was performed after 6 h.

Another reason for the development of an avascular necrosis of the femoral head is the increased intraarticular pressure in the hip joint [14], which averages 12 mm Hg under normal conditions. Inter alia, the intraarticular pressure depends on the position of the femoral head in the acetabulum; it is at its lowest in 70° flexion and at its highest in 15° internal rotation. Furthermore, the intraarticular pressure has a mean value of 23 mm Hg in extraarticular fractures and a mean value of 30 mm Hg in intracapsular fractures, the latter achieving its maximum 7–24 h after the accident. Hematoma aspiration with joint puncture reduces the intraarticular pressure to an average of 4.6 mm Hg.

In the present state of knowledge, a relieving joint capsule incision is indicated in children and adolescents during the treatment of the femoral neck fracture. Undoubtedly, this intervention has to be combined with the performance of the osteosynthesis within 6 h. For elderly patients, an intraoperative puncture of the hip joint is sufficient for relieving the intracapsular hematoma, as long as a large bore puncture needle is used.

Nevertheless, it is not clear whether time and type of mobilization have a significant influence on the development of avascular necrosis of the femoral head. According to a collective study the necrosis incidence has to be expected as follows:

Time of the femur head necrosis	Percentage
Up to 3 years	69
Between 3 and 6 years	16
Between 7 and 10 years	14
After 10 years	1

A patient population of our department revealed a relationship between the incidence of avascular necrosis of the femoral head and the fracture type as presented in the following table:

Type of fracture	Number of cases	AVN (*n*)	AVN (%)
Garden I[a]	81	17	21
Garden II	19	0	0
Garden III	46	9	19.5
Garden IV	8	3	37

[a]With and without secondary loosening of the impacted fracture. A total of 399 patients with an average age of 69.5 years suffering from 406 femoral neck fractures were surgically treated between 8/1992 and 12/1996. They were evaluated in a follow-up period of 2.6 years. The mortality after the first year was 30.6 %

Based on comparative studies, some researchers state that the large diameter (diameter of the head screw DHS 14 mm vs. screw diameter of 7.5, 8.5, or 9.5 mm) of several implants provokes avascular necrosis of the femoral head, but definitive proofs are not available at present.

Determination of Femoral Head Vitality

The following procedures are presented in order to verify or eliminate an avascular necrosis of the femoral head.

MRI

In the case of titanium implants, the necrotic section can be displayed directly due to the fact that the water content of the necrotic and the vital area is different. The disadvantage of this noninvasive and reliable method is the fact that patients with steel implants, even in other parts of the body, cannot be examined.

CT

Deformities and impaction can be visualized in a series of X-ray computer tomography images of the hip joint with coronal and sagittal cross-sections. The advantage of a CT is that it is a routine method. Nevertheless, high exposure to radiation and the fact that it is only 100 % reliable after manifestation of the necrosis have to be considered as disadvantages.

Scintigraphy

After a tracer is administered intravenously, its decreased uptake in necrotic areas is apparent on the scan image. This technique is unreliable to detect early stages and is of no importance today. Especially performed as scintimetry, it should only be used by an experienced examiner.

SPECT

SPECT does not belong among the routine methods to diagnose a femoral head necrosis. Only sporadic studies are available in the literature.

Laser-Doppler Flowmetry

This is based on the fluoroscopic registration of an intra-osseous bleeding after drilling into the cranial part of the femoral head with a laser probe. It cannot be recommended as a routine diagnostic tool, but it can be used intraoperatively in order to detect blood supply of the drilled region. However, it is not possible to use it as a quantitative measurement to decide whether or not the blood supply is sufficient.

Pseudarthrosis (Nonunion) and Its Treatment [3, 9, 10]

Apart from avascular necrosis of the femoral head, nonappearance of fracture healing after a femoral neck fracture is a common complication of osteosynthesis. It is caused by adverse mechanical conditions. Depending on its definition, the incidence lies between 10 % and 30 %.

After appearance of clinical symptoms, which are generally not any different from those of an avascular necrosis of the femoral head, and after diagnosis of the pseudarthrosis using X-ray, a verification of the vitality of the femoral head is absolutely necessary. If it is vital, a mechanical analysis of the X-ray has to be performed to be able to detect the possible reason for the development of the pseudarthrosis. In most cases, a bending and rotational movement is responsible. The fracture plane in the a.p. view is usually a steep one.

Using the correct analysis method, an accurate solution can be found to eliminate the bearing shear forces on the pseudarthrosis site using a *intertrochanteric valgisation* correction osteotomy. The necessary correction angle lies between 15° and 20°. The osteotomy has to be planned accurately and graphically defined in a way that an appropriate result after fixation of the chosen implant (angular blade plate) can be achieved. Of course, the goal is to deflect the load and to allow compression on the pseudarthrosis site with the best possible leg length equalization (Fig. 19.5).

In severely dislocated femoral neck fractures in young patients, open reduction and primary valgisation with an angular blade plate can be considered (Fig. 19.6).

If the vitality of the head is partially impaired, age-related measures such as drilling into the femoral head or bolting in of a vascularized graft with vessel stem (e.g., relocating the crista trochanterica according to Judet and implanting it dorsally in a prepared bed on the femoral neck) is suitable for younger patients, whereas total hip replacement is advised for elderly ones. With increasing damage and patient age, the indication for a total hip replacement will be set more often.

Reoperation Rate

Osteosynthesis is used in about 20 % of all femoral neck fractures. The need for blood substitutes during the operative and postoperative phase is definitely far lower using this type of treatment. Furthermore, it has a lower rate of infection, a lower inpatient- (5 %) and 1-year-mortality rate (25 %), as well as a lower Harris hip score during the first 12 postoperative months. Nevertheless, only 60 % of all the performed osteosyntheses can be classified as "uncomplicated" in their course. The other 40 % have to be reoperated. These results are partially caused by the local organizational usages, a too high tolerance of mistakes during primary care, and an indicative intolerance.

Wang et al. [18] conducted a meta-analysis including 15 studies. They were able to determine a reoperation rate of 23 % in the first year and of 42 % after 2 and 5 years, respectively, whereas the mean reoperation rate in our own patient population after a follow up of 2 1/2 years was 18.6 %.

19.7.2.8 Implant Removal

The older the patient, the less an implant removal is indicated. Especially in implants with a large diameter, a collapse of the femoral head can occur after removal. In contrast, the removal of screws is much easier and safer if they are causing any complaints

19.7.2.9 Hip Hemi-Arthroplasty (HHA)

Indication

Consensus was found that, for primary care, hemiarthroplasty was offered to patients with a biological age of more than 80 years with a Garden II to IV and Pauwels III fractures. The reasons are:

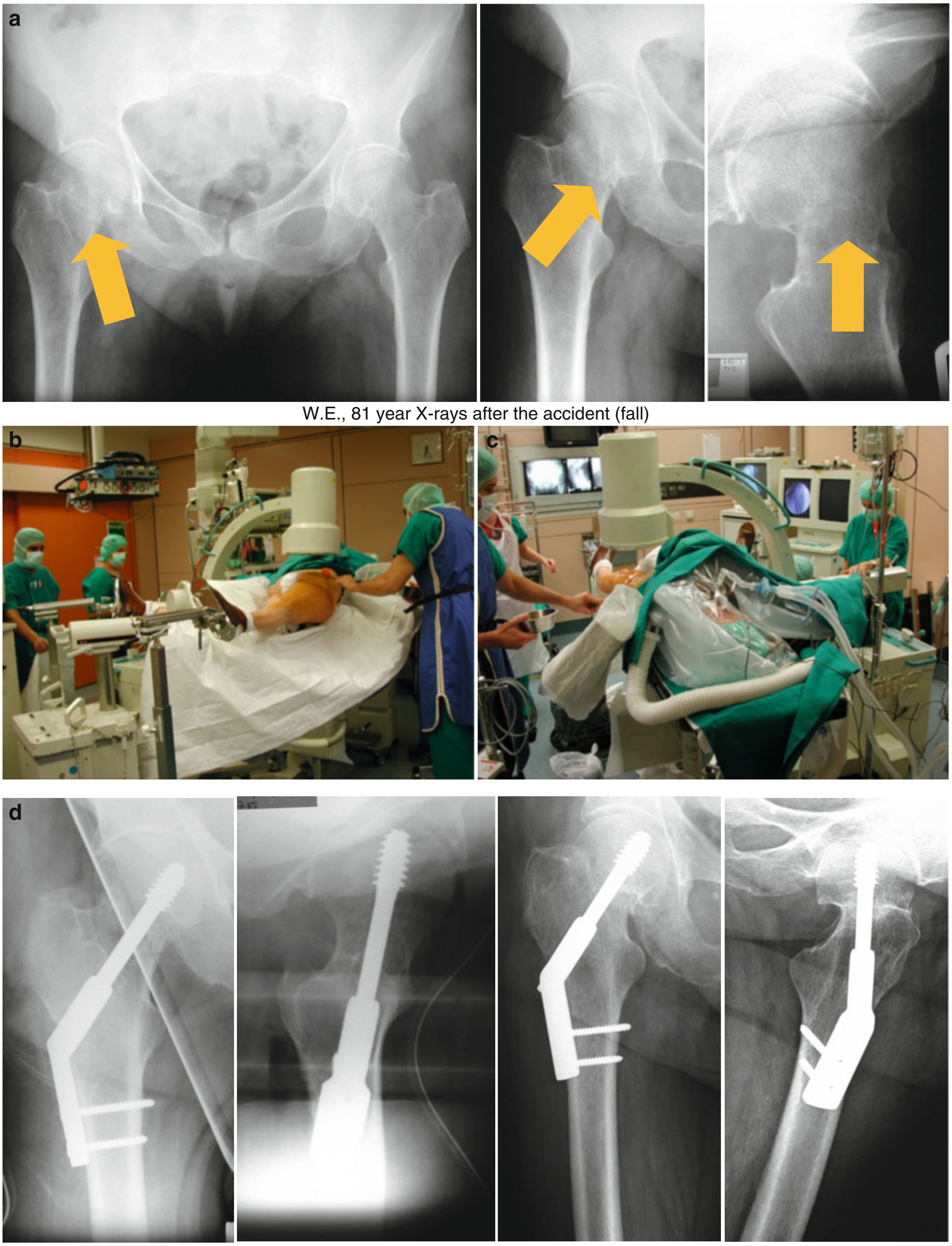


Fig. 19.5 Closed reduction and internal fixation (CRIF) of a femoral neck fracture on traction table, with two-image intensifier inserting a dynamic hip screw (DHS). (**a**) Primary X-rays of a Garden type I femoral neck fracture. (**b**) Positioning on the traction table in slightly abducted in internally rotated leg on both sides. (**c**) Positioning of both image intensifier. Anatomical reduction of the fracture fragments in both, a.p. and axial plane. (**d**) Postoperative X-rays and X-ray control after 4 weeks

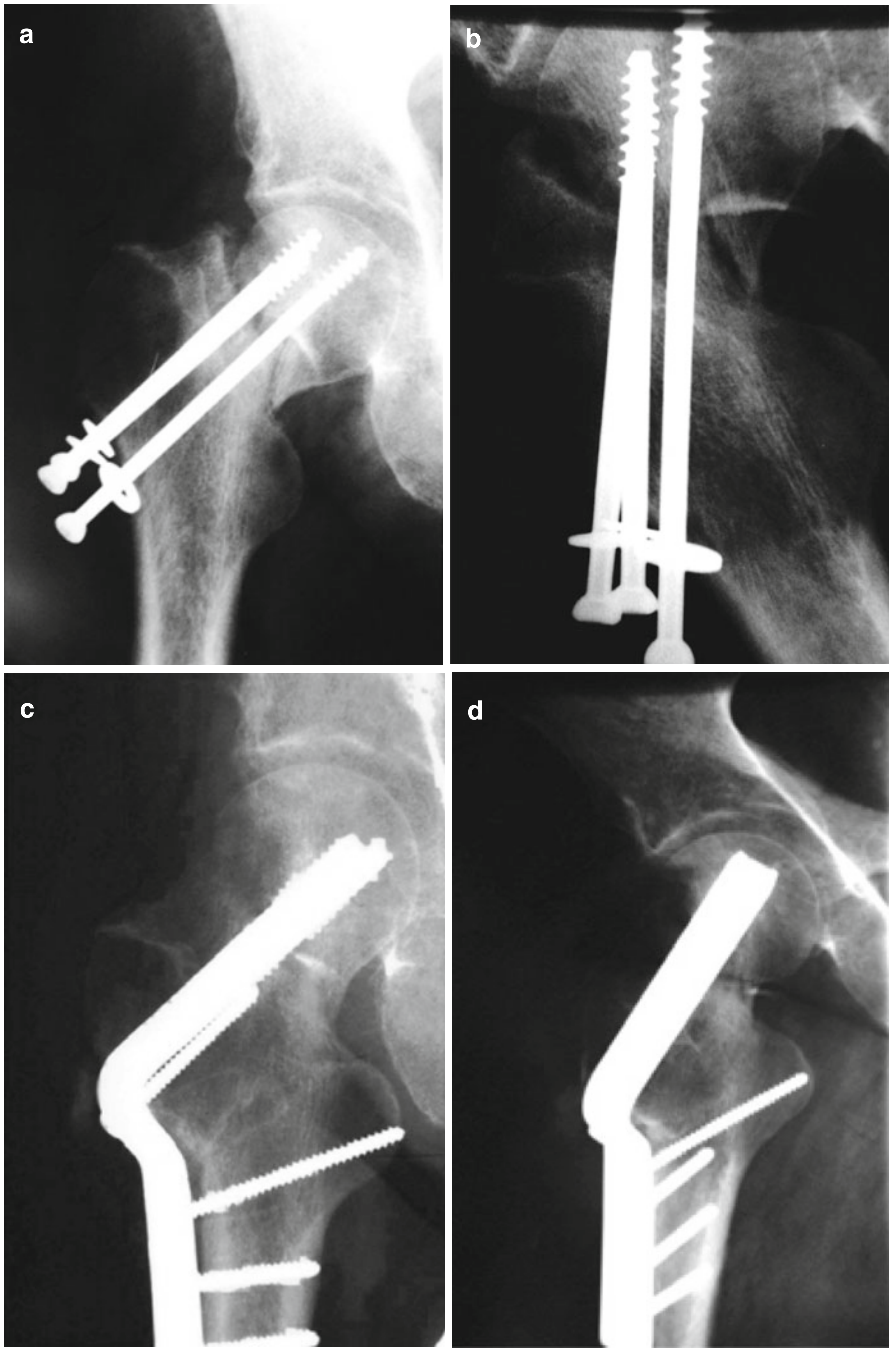


Fig. 19.6 Twenty-four weeks after accident, loosening of screws, nonunion (**a**, **b**) Valgisation osteotomy, healing of osteotomy and of the nonunion, X-rays 1 year after accident (**c**, **d**)

- Shorter surgery time due to the fact that the acetabulum must not be prepared
- Less blood loss
- Lower intra- and postoperative mortality
- Lower infection rate and lower dislocation rate compared to a total hip arthroplasty
- Lower implant costs
- The untreated healthy hip socket resists the artificial femoral head in a sufficient way
- Normally, a painful socket protrusion does not occur in most cases and, even if it does, an acetabular component can be implanted if necessary

Because hemi-arthroplasty had enabled millions of patients to move free of pain for a long time period, the arguments presented above have to be considered correct.

The indications for primary hip hemi-arthroplasty include:

- High biological age (>80 years)
- Garden III and IV, Pauwels III fracture type
- Tolerable operative risk
- Existing compliance
- Probability of regaining the ability to walk

19.7.2.10 Operative Techniques

Anesthesia

The choice of the procedure depends on surgical aims and approaches (see Sect. 19.7.2.3).

Positioning

The positioning of the patient on the operating table depends on the chosen surgical approach:

Antero-lateral Approach (Watson-Jones)

Opens the way to the hip joint from anterior. Skin incision will be performed lateral parallel to femoral shaft. After division of the tensor fasciae latae and the fascia along of the direction of their fibers, the tensor will be lifted up anteriorly and the M. gluteus medius retracted porteriorly. The M. vastus lateralis will be incised longitudinally over the tuberculum majus and left in continuity with the fibers of the gluteus medius. The capsule oft he hip joint is presented. After incision of the capsule the access to the hip joint implemented.

The Postero-lateral Approach, Southern Approach (Kocher-Langenbeck)

Enables the access the the hip joint from dorso-lateral. After division oft he skin, the subcutanous tissue, the splitting of the fascia, tensor faciae latae and M. gluteus maximus in longitudinal direction (following their fibres) opens the way to the short external rotators of the hip and M. quadratus femoris. After their dissection near to the femoral insertion site and retraction of the muscle bellies to dorsal the capsule oft he hip joint can be visualized. With opening the capsule the bony components oft he hip joint are accessible.

Minimally Invasive Approach

This approach can only be used to treat femoral neck fracture in slim patients, resulting in reduced postoperative morbidity compared to the "extended" approaches. It can be executed as a minimally invasive antero-lateral or lateral approach, keeping in mind that it cannot be recommended for inexperienced surgeons. Furthermore, special instruments may be required.

Implantation Techniques

Cemented Technique

The femoral component will be stabilized by methylmethacrylate into the femoral medullary canal as an intermediate laminate between bone and metal.

Cementless Technique

This requires an exact preparation of the medullary cavity, because the stem has to be inserted into the spongiosa in a press-fit manner enabling a complete wedging of the stem. As a consequence, micromovements between the implanted stem and the bone should be impeded. Because of the special processing of the surface (sandblasting, microporotic coating, hydroxylapatit coating, etc.), apposition growth of the bone against the prosthesis should occur resulting in a complete ingrowth. Therefore, it is crucial that no gaps between the bone of the metaphyseal femur and the surface of the prosthesis remain. They have to be eliminated by filling them up thoroughly with spongiosa.

Micro-motion causes the cementless stems to "glide" very slowly in a caudal direction over the course of time until they become stuck again. This process is responsible for pain sensations that can occur from time to time in the distal femur. Because of the excellent long-term results, cementless hip arthroplasty can be recommended as a routine procedure for patients with a longer life span.

Head Types

The mechanical qualities of a solid "hemi-head" made of steel, as well as of a "dual head" (a regular steel head with a diameter of 28 mm or 32 mm is placed in a polyethylene hollow head surrounded by a metal coat), exceed by far the demands that have to be provided by a hip joint head positioned in an anatomical socket. Therefore, it is just a matter of time, combined with the load intensity, until this mechanical mismatch will lead to a yielding of the anatomical socket. For a solid head, a time period of approximately 5 years is estimated until this complication occurs, whereas the usage of a dual head can help to prolong this period significantly. The decision regarding which head type is used for the hemiarthroplasty is based on the patient's estimated life span.

19.7.2.11 Postoperative Treatment

Mobilization

On the first postoperative day, the patient is placed in a sitting position on the edge of the bed. After the drains have been removed the patient is allowed to make the first attempts to walk with the help of a walking frame. Non-weight bearing of the affected leg is only prescribed in rare cases, knowing that the treated patient population, due to their age, may not be able to follow these instructions. Additionally, physical therapy and follow-up treatment are required. Primary X-ray control should be performed in the OR and before the patient is discharged.

19.7.2.12 Complications

Intraoperative Complications

Damage to the Femoral Vessels

During preparation of the socket, a Hohmann retractor is usually inserted into the anterior acetabular rim. Because the a. femoralis communis runs close to the anterior border of the acetabulum, it can be damaged by the tip of the retractor, causing immediate bleeding after its removal. If the source of the bleeding can be localized, the artery should be dissected and treated using another incision ventrally.

Damage to the Femoral Nerve

Damage to the n. femoralis can occur under similar conditions as presented above. It is caused by compression of the retractor onto the nerve. If an innervation failure of the m. quadriceps femoris is detected postoperatively without any remission tendency, a revision of the canalis musculorum and a dissection of the n. femoralis are indicated.

Peroneus Paresis

This is caused by traction damage during the presentation of the shaft using an antero-lateral approach. Usually, obese patients are affected. Because of the heavy weight of their leg, it is difficult for the assistant to position it properly during the surgery, with the result that he/she pulls more on the leg than he/she lifts it. In consequence, a bad prognosis must be assumed. A complete, spontaneous remission is time-consuming and rare. Surgical revision is unrewarding because no reparable pathological differences can be found in the pathway of the n. ischiadicus. Revision does not alter prognosis and course.

Insufficiency of the Gluteal Musculature

This is a consequence of damage to the n. gluteus superior. Approximately 8–10 cm proximal to the trochanter area where the gluteal musculature is split, the n. gluteus superior with its accompanying vessels cross from posterior to anterior. In cases where the muscle fibers are pulled apart excessively, the vessels can tear, resulting in severe bleeding. If this happens, mass coagulation should not be attempted because it could cause nerve damage. In order to protect the n. gluteus superior, searching for the disrupted vessel and selective coagulation is preferred. Not following this advice, an insufficiency of the gluteal musculature can be the consequence; it is detectable by a positive Trendelenburg's sign. Undoubtedly, preventing the damage is more successful than any attempts to repair it.

Leg Length Discrepancy

This is the result of implanting the prosthesis too deeply into the medullary cavity. Only a leg length difference of 10–15 mm is tolerable. Values beyond this interval have to be considered as a planning failure. Generally, accurate preoperative planning is possible if the contralateral hip joint is intact and can therefore be used as a template. Furthermore, adequate schematic drawing, exact positioning of the patient on the operating table, and appropriate coverage of the surgical field facilitate the performance of the surgery. With the help of the inserted rasps for the stem and of attachable trial heads, the surgeon can assess the length proportions intraoperatively. Reference points like the medial malleolus of the affected and contralateral side can be used to achieve equal leg length prior to the implantation of the definitive prosthesis.

Postoperative Complications

Thromboembolism Prophylaxis

The implantation of an arthroplasty is connected with an increased risk of thrombosis and embolism, especially if the surgery is not performed immediately after the accident. An effective thrombosis prophylaxis using, for example, low-molecular-heparin should be prescribed on a routine basis.

Postoperative Dislocation

For all hemi-arthroplasties implanted after femoral neck fractures, a dislocation occurs in 2 % of the cases. The reasons are

- Complete resection of the hip joint capsule with damage to the limbus articularis

- Avulsion of the socket edges or parts of the wall due to retractor pressure during preparation
- Mismatch of the implant and the lengths
- Real traumatic dislocation due to a new fall

Generally, primary dislocation occurs within the first 4–6 weeks after surgery. If the acetabular defect can be verified using X-ray, if the hip joint is unstable after reduction, and if an enlargement of the joint space (indicating an interposition) is observed, a re-operation is indicated. By implanting an acetabular component, the hemi-prosthesis has to be converted into a total endoprosthesis in our opinion. Furthermore, a re-operation after hip dislocation must principally be considered if an avulsion fracture of the trochanter major exists.

In the case that diagnostic assessment reveals a basically correct result and that the "hip joint" seems to be stable after reduction under analgesia, a split lower leg cast with side booms for rotation control should be applied and bed rest is prescribed for 2 weeks. Alternatively, a hip orthosis should be adjusted to enable mobilization.

Postoperative Infection and Its Prevention

After the implantation of a hip hemi-arthroplasty, postoperative wound infections (superficial infections, subcutaneous fat necrosis, epifascial infections, and wound healing disorders) occur in 4–5 % of the cases. In 1–2 %, the infection affects the entire hip joint (deep infection) with accompanying more or less extensive tissue necrosis (fascia, musculature) – either as a cause or as a result of it. Apart from a few exceptions, an early and consequent wound revision with debridement and drainage is advisable.

To prevent postoperative infection, we recommend the use of perioperative antibiotic prophylaxis.

Pain, Protrusion, Revision Surgery

Pain that especially appears after a longer time period after the hemi-prosthesis implantation can be caused by the following:

- Increasing cartilage damage and "deterioration" of the acetabulum
- Protrusion of the acetabulum
- Loosening of the prosthesis

All mentioned pathologies require detailed diagnosis as they are accompanied by very clear or very reticent clinical symptoms. Five years after implantation, the percentage of acetabular erosions detected by X-ray is 20 %, whereas the majority of the patients are not complaining of any discomfort. In the literature, the number of surgeries requiring revision is stated to be 5–25 %.

In case of problems caused by the hip socket, the secondary implantation of an acetabular component is advised. If the stem is loosened, it is recommended to convert the prosthesis into a total hip arthroplasty.

19.7.3 Total Hip Arthroplasty

19.7.3.1 Indication

Implantation of a total hip arthroplasty is primarily used for patients with a biological age of up to 60–75 years suffering from highly displaced fracture types Garden III and IV/Pauwels III. Because life expectancy of patients in this age category is about 15 years or more, everything possible should be done to enable the highest achievable durability of the implant in order to avoid revision surgery for as long as possible. As a secondary procedure, a total hip arthroplasty is implanted into patient if the attempt of osteosynthesis has failed or if an avascular necrosis of the femoral head has developed.

19.7.3.2 Operative Techniques

The operative techniques referring to the positioning of the patient and the possible approaches do not differ from the last chapter (see Sect. 19.7.2.10). Of course, it is absolutely necessary to perform preoperative planning using a sketch prior to the actual implantation.

The implantation of a total hip arthroplasty starts with the insertion of the acetabular component, meaning that, after performing the osteotomy of the femoral neck and after the removal of the head-neck fragment, the joint capsule is removed completely including the labrum acetabuli and the tranversum acetabuli ligament. These steps are particularly important if a cementless threaded cup or a spherical press-fit cup is used. The incisura acetabuli has to be thoroughly released from ligament residuals and from soft tissue. Then the cartilage surface of the acetabulum is scraped clean using a large, sharp spoon. Afterwards, the acetabulum is centered and prepared using a spherical bur until the acetabular surface bleeds homogenously. Now, the cup of the designated size can be inserted. The following cup forms are available:

- Cemented polyethylene cups
- Titanium metal baked press-fit spherical cups, with the possibility of additional screw fixation; inlays made of polyethylene, ceramic, and polyethylene with a metal coating

- Titanium threaded cups with the inlays mentioned above

After implantation of the titanium cup component in a 45° inclination and 10° inversion, a trial inlay is inserted, the socket is stuffed with gauze to protect it, and the femur is prepared. An X-ray can be performed with the trial components to ensure that the implant's length, stability, and position are accurate. After implantation of the femoral components, the so-called, pre-planned "tribological pairing" is realized. Basically, the following combinations are feasible:

- Metal head vs. polyethylene cup
- Ceramic head vs. polyethylene cup
- Ceramic head vs. ceramic cup
- Metal head vs. metal cup

Heads with a diameter of 32 mm are preferably used in Europe; the cups are adjusted to this standardized size. Basically, head sizes of 36 mm, 28 mm, and 26 mm are available. The danger of impingement, the probability of dislocation, and the tribological behavior (more dependent on the material than on size) of the implant depend on the designated head size.

In our opinion, the cementless implantation technique is preferred.

19.7.3.3 Postoperative Treatment

Postoperative treatment for endoprosthetics is more or less standardized: first dressing change and drain removal after 48 h postoperatively. Mobilization starts on the second postoperative day using a walking frame or crutches. X-ray control is performed after mobilization. The older the patient, the greater the probability that mobilization with full-weight bearing is prescribed; the younger the patient, the more likely is a mobilization with non-weight bearing for 2 weeks followed by an increase to 20 kg partial-weight bearing, reaching full-weight bearing after 8 weeks. The second X-ray control should be performed after 4 weeks, 3 months, 6 months, and 12 months.

19.7.3.4 Complications

The complication rate is significantly higher in traumatically caused total hip replacements compared with elective ones.

Postoperative Infection and Prevention

Wound healing disorders usually appear during the first two postoperative weeks. The surrounding area of the surgical wound is inflamed, painful, and swollen. Fever and leukocytosis are not uncommon, but an increase in CRP is found on a routine basis. The most common cause, especially in obese patients, is an epifascial fatty tissue necrosis. Of course, the decision as to whether a wound healing disorder needs surgical revision or if it can be treated conservatively can be difficult, especially if the clinical appearance of the wound shows improvement and if the body temperature normalizes after the first administrations of antibiotics. If wound secretion occurs or if the antibiotics do not cause any improvement, surgical wound revision is advised in case of doubt.

Of interest, the incidence of wound infection is given as 2 % and of deep prosthesis infection of 3 %.

To avoid postoperative infection, it is advised to prescribe a perioperative prophylaxis with broad-spectrum antibiotics. If a total hip arthroplasty is implanted after previous osteosynthesis, or if a hip hemi-prosthesis is secondarily changed into a total hip prosthesis, the antibiotic prophylaxis should be prolonged to 3 days postoperatively, especially if the patient is older than 70 years.

Postoperative Dislocation

A dislocation of a total hip arthroplasty (used for the treatment of a femoral neck fracture) occurs in 10 % of all cases and is therefore the most common complication. In order to prevent a dislocation, patients are instructed not to cross their stretched legs (during the night a pillow should be placed between the legs). A squatting position must be avoided (e.g., elevated chairs and car seats with a cushion, toilette seats with a special attachment). Furthermore, they are not allowed to pick up something from the floor while bending the upper body forward. Patients may not put on their stockings or socks in the usual manner by bending the hip and knee joint with external rotation of the hip joint.

The dislocated joint has to be reduced under general anesthesia or with anesthesia near to the spinal cord. Afterwards, the stability of the joint must be evaluated. The following questions have to be answered:

- Is it not possible to dislocate the joint by leg manipulation?
- Is it easy to dislocate the joint again and in what kind of position?
- According to the X-rays made after reduction, is it possible to see any implant-specific technical error that can be responsible for the dislocation? (A CT analysis may be indicated later on for further clarification.)

- Did any fractures occur during the dislocation and/or reduction that could have an effect on the stability?

If the joint proved to be stable after reduction, mobilization on crutches with full-weight bearing can be started with regard to the preventative measures. It has to be clear to the patient that another dislocation could happen. In all other cases, revision surgery has to be offered.

Revision Surgery

The aim of revision surgery is to correct an inaccurate positioning of the implant or to replace components because of mechanical failure. Under the following criteria revision surgery is indicated:

- Recurrent dislocation of the artificial joint
- Inaccurate implantation of the joint components (cup > stem)
- Loosening of the individual components
- Breakage of the components
- Periprosthetic fracture (loosening of the components?)

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Pertrochanteric Fractures 20

Vilmos Vécsei

20.1 Basics

Pertrochanteric hip fractures usually are provoked by uncontrolled falls. Risk factors are female gender, osteoporosis, Caucasian race, moderate to severe obesity, and limited mobility during activities of daily living. As the population's mean age shifts upwards, especially in Europe, he incidence of pertrochanteric hip fractures has increased. In the European Union, in 2000, out of a population of approximately 360 million residents, 500,000 people (400,000 females and 100,000 males) suffered from a proximal hip joint fracture. Assuming a constant number of inhabitants, almost twice as many cases are expected (950,000: 750,000 females and 200,000 males) in 2050.

20.1.1 Pathophysiology

Pertrochanteric hip fractures in adolescent patients is rare. They are caused by high-energy impact, which leads to multiple injuries or polytrauma. In this scenario, subtrochanteric fractures are more common than pertrochanteric ones. In older patients, pertrochanteric fractures are more common. They are usually the result of low-impact injuries such as falls. Nevertheless, patient prognosis depends on the concomitant injuries rather than on the trochanteric fracture itself in both cases [1, 8, 16, 60].

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Pertrochanteric fractures are typified by the following:

- Age of patient in the seventh to eighth decade
- Women are affected three times more often than men
- Co- or multimorbidity often exists
- In general, walking ability, range of motion, and activities of daily living are already limited prior to the accident
- Bone quality is reduced
- Patients may lose their independence
- In comparison to femoral neck fractures, the morbidity is higher because of a higher impact, resulting in greater tissue damage
- The fracture itself has a good healing capacity
- As the blood supply in the metaphyseal bone is good, avascular necrosis of the femoral head rarely occurs (2 %) [5, 9, 10, 24, 39, 44, 70].

20.2 Clinical Findings

Because of the loss of weight-bearing transmission capacity in the fractured femur and as a consequence of an imbalance of the inserting musculature in this area, there is a tendency for varus displacement. This usually leads to shortening of the femur. At the same time, the leg is externally rotated, perhaps caused by pain prophylaxis. Undoubtedly, the clinical appearance itself is not sufficient to distinguish between a pertrochanteric hip fracture and a femoral neck fracture. A hip fracture can remain undetected because pain caused by a fracture around the hip can radiate and be present only at the lower part of the femur or the knee joint.

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20.3 Diagnostics

20.3.1 Conventional X-ray

X-rays in two planes (anteroposterior, or a.p., overview image of the pelvis and axial view of the affected hip joint) allow an accurate diagnosis in almost every single case (98 %).

20.3.2 Computed Tomography (CT)

If the clinical appearance and the pain localization points to pathology around the hip joint, but the X-rays do not show a definite fracture, a CT scan with coronal and sagittal plains should be performed to rule out any bony injuries.

20.3.3 Magnetic Resonance Imaging (MRI, MRT)

MRI is unnecessary to detect a fracture on a routine basis. However, for specific differential diagnosis of pathological or fatigue fractures, the MRI is a helpful radiological diagnostic tool.

20.4 Classification

The main differentiation of the fracture type is made on the basis of mechanical characteristics, meaning that it is divided into a stable and an unstable fracture form [9, 49, 68]. Of interest, 65–75 % of pertrochanteric hip fractures are classified as unstable.

The stable form includes fractures with more or less unchanged, correct alignment of the femur, without any shortening or lengthening, as well as fractures in which the original axis and length of the femur can be retained without any further manipulation after initial reduction.

The unstable form consists of fractures that always tend to slip into to an incorrect position. In consequence – despite several reduction maneuvers – a persistent axis deviation is unavoidable. “When there is cortical instability on one side of a fracture as a result of cortical overlap or destruction, the fracture tends to collapse in the direction of such instability” [19, 20].

Table 20.1 Petrochanteric fractures – AO classification

A 1: *Simple* (*two-fragment*) *pertrochanteric fractures*
A1.1 Fractures following the intertrochanteric line
A1.2 Fractures through the greater trochanter
A1.3 Fractures below the lesser trochanter
A 2: *Multifragmentary pertrochanteric fractures*
A2.1 With one intermediate fragment
A2.2 With two intermediate fragments
A2.3 With more than two intermediate fragments
A 3: *Intertrochanteric fractures*
A3.1 Simple, oblique
A3.2 Simple, transverse
A3.3 With a medial fragment

Dislocation tendency of the fragments is clearly linked with the fracture form:

- *Reversed* fractures (the medial and lateral corticalis is interrupted) often occur in combination with an avulsion of the greater trochanter. They can result in a medialization of the shaft fragment.
- If the medial and posterior corticalis is broken, as often seen in vertical oblique fractures with multiple fragments, a medial comminution results in a varus malposition, a posterior comminution results in a retroversion and external rotation, whereas a lateral comminution (avulsion of the trochanter major) results in a shaft medialization [52].

Unstable fractures usually not only cause great difficulties in achieving an exact anatomical reduction, but the risk of secondary displacement after fixation of the fracture is also increased (Figs. 20.4 and 20.5).

From the numerous classifications systems developed between 1949 and 2002, the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification [49, 68u] is the one most commonly used today (Table 20.1). Basically, A1 fractures are stable and A2 and A3 fractures unstable. Nevertheless, it is still controversial if this classification fulfils all the needed requirements. Whereas it is quite easy to categorize the fractures into the main groups A1, A2, and A3, the allocation into the subgroups is often irreproducible and unsatisfactory, implicating that a comparison of different treatment modalities is not really possible.

Osteoporosis must be included in the classification scheme because it influences the outcome of fractures near the hip joint, especially in pertrochanteric fractures because the anchorage of specific implants depends on it. The osteoporosis classification of Singh [64], in the context of fractures near the hip joint, is based on the permeability of the trajectories in the femoral neck and femoral head as well as on their quality in conventional X-ray images. It is divided into six grades (I to VI). Grade VI represents a normal-appearing hip joint with trajectories clearly seen on the X-ray, whereas, in grade I, trajectories can only be detected in the caudal areas of the femoral neck and head.

Generally, the failure rate depends on three important factors:

- Degree of instability
- Degree of osteoporosis
- Surgical skills

While an implant failure rate of 1–9 % is to be expected in stable fractures, it increases to 2–26 % in unstable ones [14, 18, 35, 38, 39, 42, 70, 76]. Therefore, an adequate choice of the implant and a high quality of operative care are crucial.

Implants for osteosynthesis fail more often in the lower Singh grades (Singh I, II, III) than in the higher grades (Singh IV, V, VI). Therefore, the probability of osteosynthesis failure is very high in A2 or A3 fractures that are classified by Singh grade I to III. By correct reduction and correct implant positioning, the failure rate can at least be reduced to 3.6 %.

For two reasons the osteoporosis classification according to Singh cannot be recommended without reservations:

- A high interobserver variability is evident.
- It does not correlate with the qualitative evaluation of osteoporosis using the standard method of dual-energy X-ray (DXA).

20.5 Therapy

Undoubtedly, a lack of anatomical reduction results in a fracture healing in a displaced position. This is and will always be the main reason for persistent functional limitations, which are disturbing for the patient and therefore reduce quality of life [27].

Irrespective of the choice of therapy to treat the fracture itself, a routinely prescribed thrombosis prophylaxis is necessary because of the high incidence of thrombosis, varying from no symptoms at all to severe complications like pulmonary embolism. In cases that include embolism or thrombosis in the anamnesis, a special prophylaxis is indicated [65]. Furthermore, it is advised that patients older than 70 years of age be treated perioperatively, and if necessary also postoperatively, with intravenous (IV) antibiotics to prevent or combat latent or manifest infections [7].

20.5.1 Conservative Therapy

Unstable pertrochanteric fractures can be reduced sufficiently using skeletal traction. However, the necessary 12 weeks of bed rest that follow this therapy are dangerous and inconvenient for the patient and therefore can rarely be recommended. (For traction treatment, see also Chaps. 2 and 4). Stable fractures can be reduced by using a “foam splint.” Premature end of the traction treatment (earlier than 12 weeks for adults) and further treatment with a pelvis-leg cast may lead to a secondary axis deviation in a varus position, despite good callus bridges [9, 36, 55].

20.5.2 Operative Therapy

This is the therapy of choice for trochanteric hip fractures. Basically, three different treatment options can be recommended (Figs. 20.1 and 20.2):

- Dynamic sliding systems or compression screw systems such as Dynamic Hip Screw (DHS) [34, 35, 69], with or without adjustable, attachable locking trochanter stabilization plate (LTSP) [14]; the Medoff [45] plate; or an integrated trochanteric reinforcement in the plate, such as the Gotfried [26] trochanter plate
- Intramedullary systems on the basis of the Y-nails developed by Küntscher [40], such as trochanter nails, Gamma nails [24], Proximal Femoral Nail – Alpha (PFNA) [21, 23, 62], sliding nails [22], Fi-nails, and many others
- Angled and double-angled blade plates are versatile and inexpensive implants that, in experienced hands, can solve many problems in unstable trochanteric fractures as well as in salvage procedures (Fig. 20.3) [77]. However, techniques such as the Dimon-Hughston procedure [16] or valgisation and medialization have to provide an intrinsic stability of the construct (Figs. 20.4 and 20.5).

New concepts such as percutaneus locking plates and the use of an external fixator on a routine basis are not approved yet [53, 64, 71, 72]. According to biomechanical examinations, the weight-bearing capacity of intramedullary nail systems is generally higher than those of dynamic slip systems [3, 4, 22, 34, 59]. This

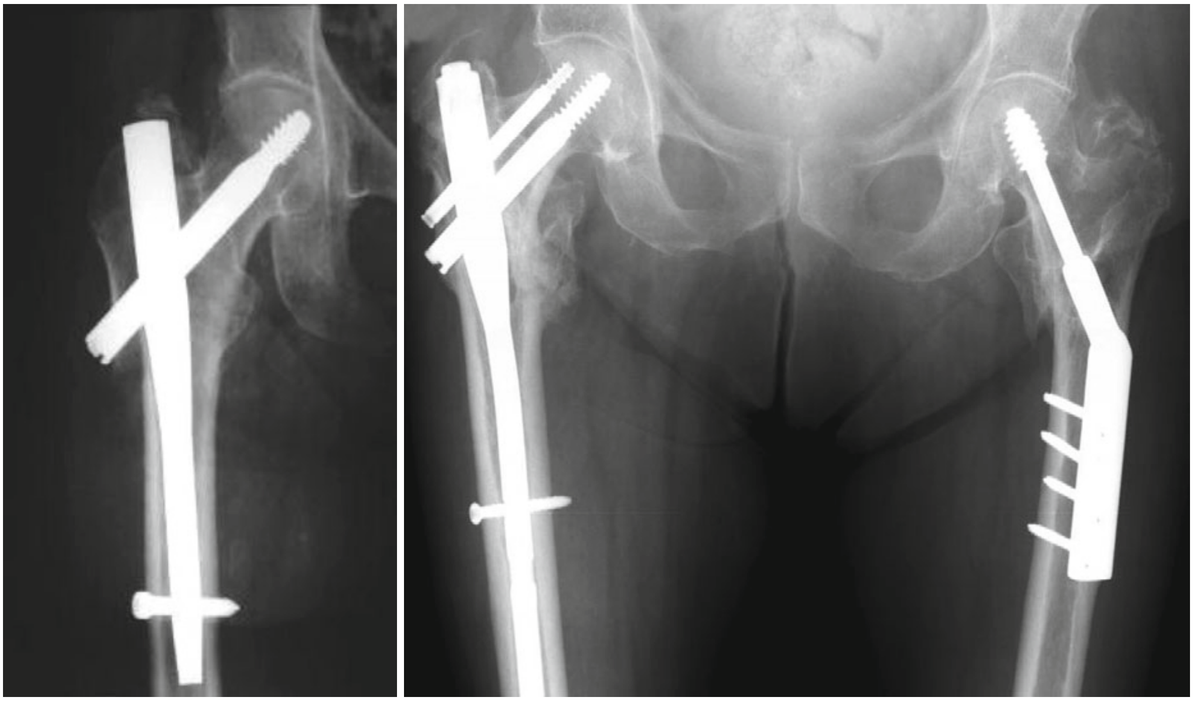

Fig. 20.1 Gamma-nail, PFN, and DHS

fact, as well as the instability of the fracture, should be considered before choosing the implant. Endoprosthetic care is only used in rare, particular cases.

20.5.2.1 Reduction

Fracture reduction is always the first step in the algorithm of operative treatment for pertrochanteric hip fractures.

Closed Reduction

Closed reduction on the traction table (fracture table) is routinely the method of choice to treat this kind of fracture. In order to guarantee sufficient leg manipulation, it is advised to connect the traction table with a high lace-up shoe. After the leg has been positioned in the shoe and connected with the plate of the traction table, reduction is facilitated and optimal manipulation can be achieved. Longitudinal traction and internal rotation are usually needed to reduce the fracture. By locking the hinges of the table, reliable retention can be guaranteed for the duration of the surgery. Whereas extramedullary osteosynthesis allows an abduction of the injured leg, intramedullary fixation should be carried out with the leg in slight adduction.

The use of two image intensifiers (a.p. and axial) should be a routine set-up (if there is enough space in the operating room) because it simultaneously enables sufficient intraoperative control of the fracture fragments and the reduction in two planes.

Open Reduction

Dissecting a pertrochanteric fracture in combination with open reduction is usually performed when closed reduction is not successful and further manipulation of the displaced fracture fragments is necessary. Nevertheless, open reduction causes vast damage to the local tissue structures in a pertrochanteric fracture and can result in extensive blood loss with persistent limited manipulation capacity of the fracture fragments. The combination of open reduction and manipulation on the traction table is a sometimes underestimated tool that can facilitate this difficult surgical step.

20.5.2.2 Stabilization

If the fracture reduction has been successful, the surgical stabilization should be performed next. The choice of the implant generally depends on the required stability and on the fracture configuration. The decision making should include the following points:

- Is osteoporosis evident? If yes, to what degree?
- Can the fracture be classified as stable? If it is unstable, what kind of instability exists?

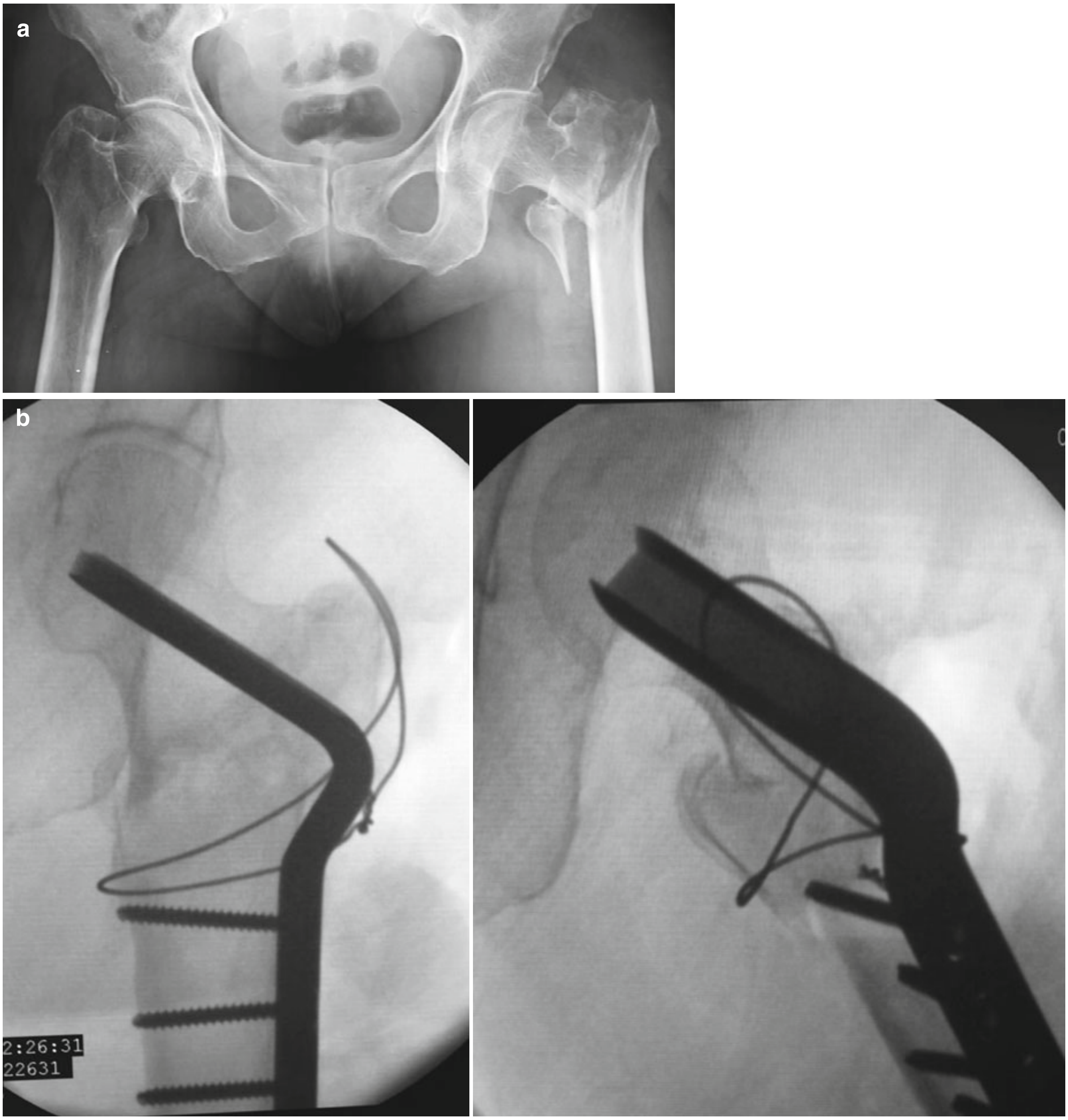

Fig. 20.2 (**a**) Highly unstable trochanteric fracture. (**b**) Fixation with double-angled blade plate and tension band wire, valgisation, and medialization

- What is the patient's general condition (biological age, general state of health, concomitant illnesses, American Society of Anesthesiologists Score (ASA) score)? [1].
  Stabilization has the following aims:
- Fixation of the fracture in an anatomical, functionally optimal position
- Postoperative full weight bearing that is free of pain should be achieved to prevent further expected complications

Extramedullary, Juxtacortical Osteosynthesis

The key point of the extramedullary plate osteosynthesis is the positioning of the lag screw in the head-neck fragment of the femur: in the anterior-posterior view it should be a little caudal to the femoral head center; in axial view, it should be posterior to the midline and parallel to the femoral neck. After placement of the lag screw, the plate slides onto the bone through the screw and is fixed to the shaft with two to four screws. The system enables the lag

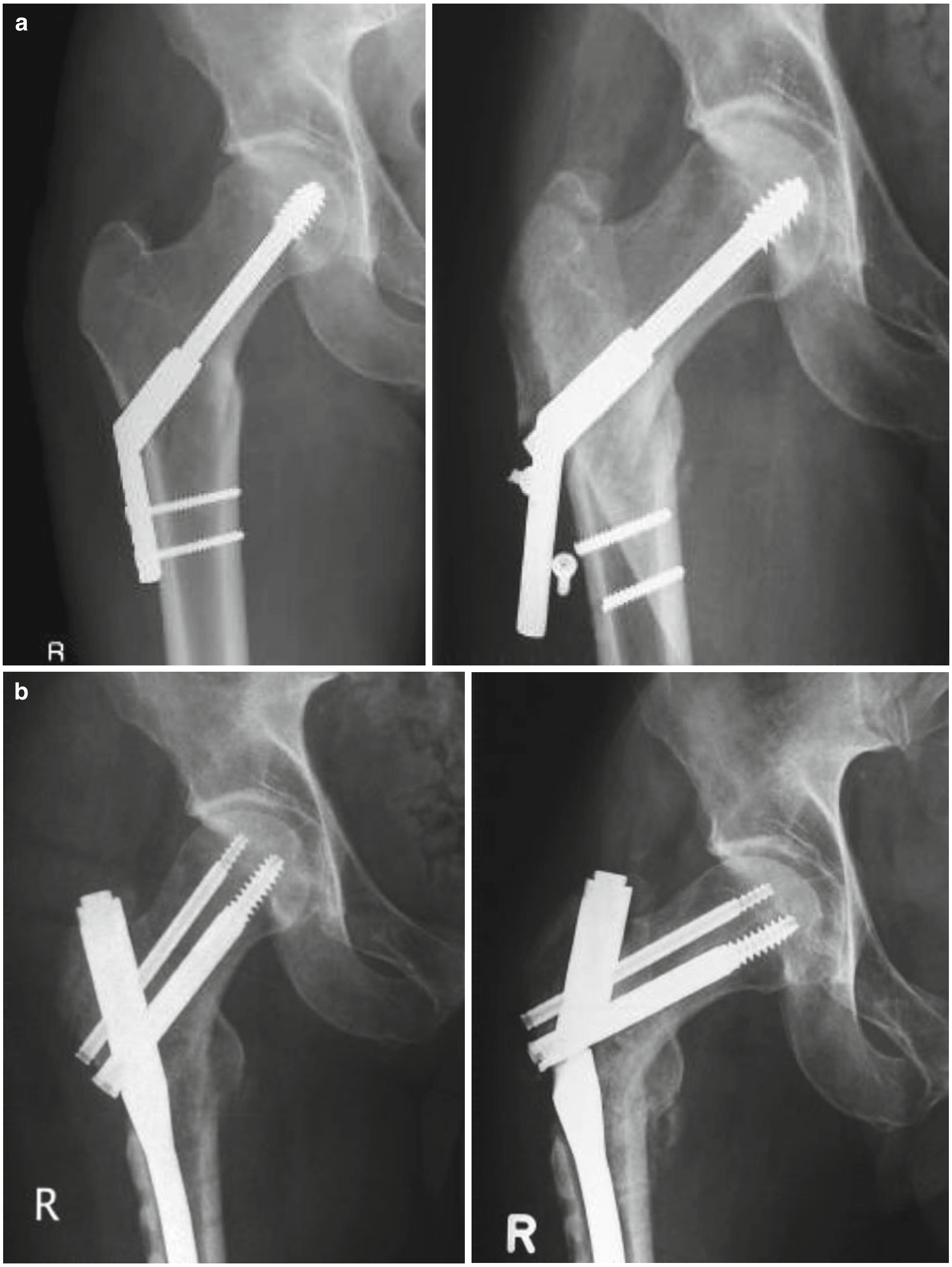

Fig. 20.3 (a) Failed fixation of a trochanteric fracture with DHS. (**b**) Salvage procedure with PFN failed. (**c**) Definitive salvage procedure with double-angled blade and intertrochanteric valgisation osteotomy and medialization

screw to glide in the conjunction of the plate. As a consequence, the risk of secondary head perforation of the screw centrally can be reduced [6, 13, 32, 34, 47, 48, 52], which is a common complication in side plates fixed to a head screw or nail system (Jewett plate, three flanged nails with side plates, etc.) [33, 76].

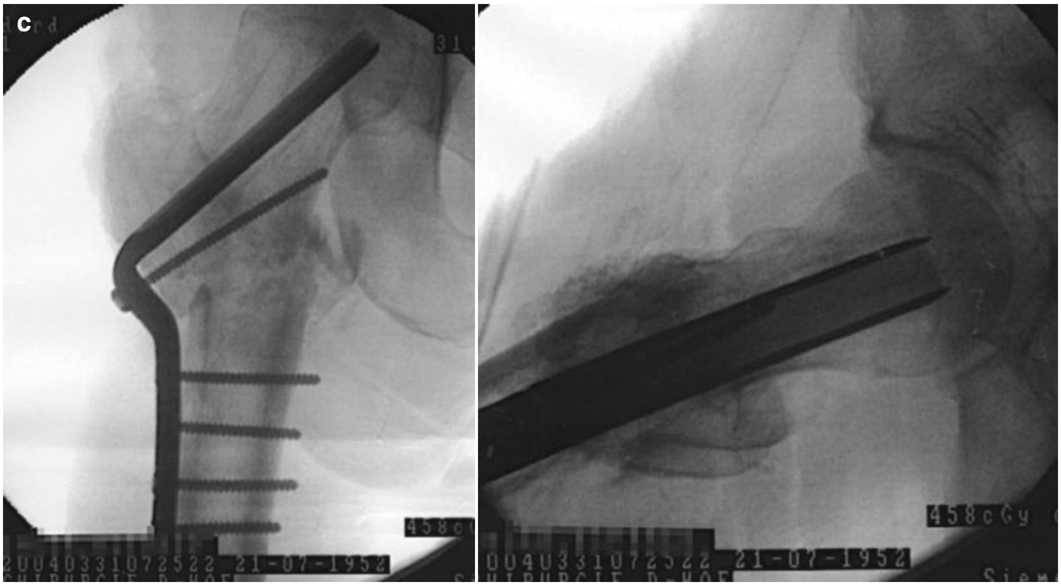

Fig. 20.3 (continued)

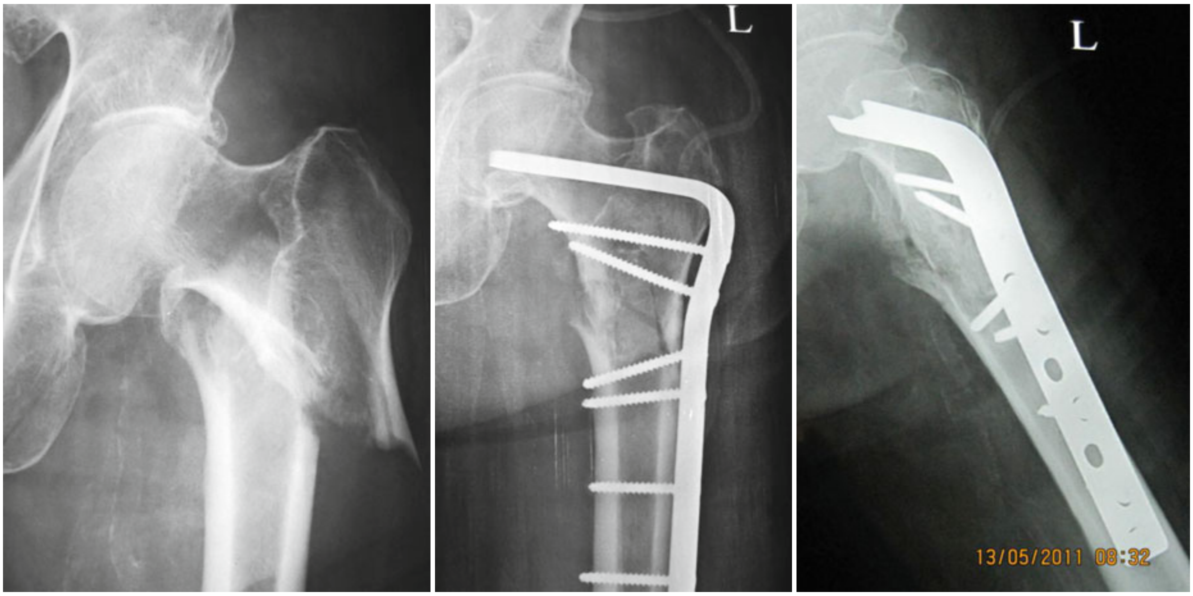

Fig. 20.4 Intertrochanteric fracture with "reversed obliquity," fixation with a condylar plate

Advantages and Disadvantages

Sliding screws, compression screws, and plate systems are easy to handle after correct application. Apart from the appropriate height of the skin incision and of the soft tissue incision, the positioning of the guide wire is an important key step. The further steps are described in detail in the chapter [19].

Concerning pertrochanteric fractures, the surgeon should be aware that the head-neck fragment might rotate during thread cutting for the lag screw. If this happens, the fragment must be secured with a second K-wire, which is positioned parallel to the guide wire. In all systems in which the head-neck fragment is secured with only one screw, it is possible that the

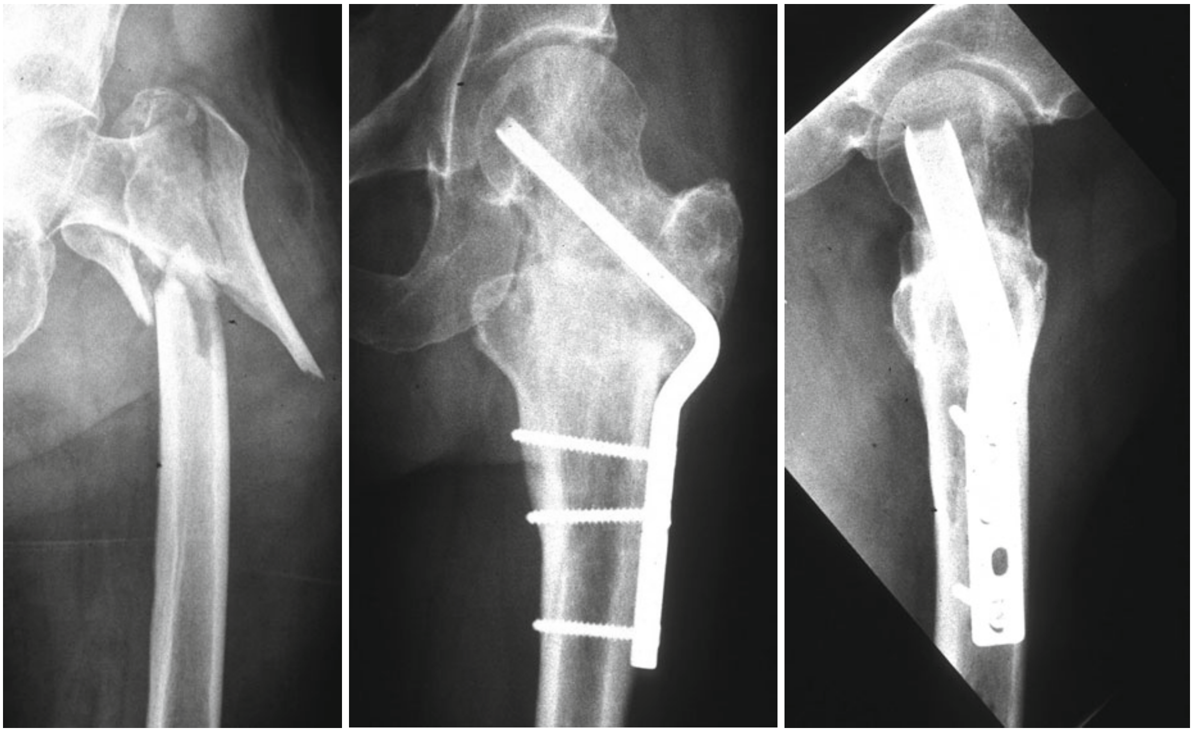

Fig. 20.5 Intertrochanteric fracture with "reversed obliquity," Dimon-Hughston procedure, fixation with double-angled blade plate

fragment rotates secondarily during aftercare, in the case that the fracture fragments do not interlock. The rotation mechanism can be prevented by using a spiral blade instead of the lag screw. In fracture forms with a shortening tendency it is also possible to medialize the shaft with a lateralization of the head-neck fragment compressed with the trochanter region, seen especially in reversed type fractures [17, 41]. Apart from shortening of the femoral neck length and from a shift of the mechanical axis of the leg, this procedure can cause clinically relevant leg shortening.

To prevent this phenomenon, the locking trochanter stabilization plate (LTSP) [14] was developed as a supplement to the DHS. It can be connected to the regular DHS plate. It offers lateral support. Furthermore, the greater trochanter is stabilized, which secures the function of the m. gluteus medius, reduces the extent of the fracture impaction in the lateral direction, and counteracts the medialization of the shaft as well as a possible secondary varus malposition resulting in leg shortening.

The Gotfried trochanter plate [26, 32] is constructed in a way that the lateral support is permanently included in the side plate and that two dynamic screws are placed in the head-neck fragment.

To prevent a secondary axis deviation and cut-outs, it is recommended to fill the lag screw as well as the metaphysical defects with bone cement. However, using bone cement on a routine basis is contraindicated as it causes local heat necrosis. Furthermore, interposition of bone cement in the fracture surfaces can lead to a delay or prevention of bone healing and it can disable further necessary, corrective procedures [2, 15, 29, 30, 42, 43] (Fig. 20.3a–c).

Complications

Type of complication	%
Intraoperative femur shaft fracture	1.0
Wound healing problems	1.0
Infection	1.0
Cut out	5–6
Pseudoarthrosis (nonunion)	12.0
Mortality within 12 months	13.0

Intramedullary Osteosynthesis

The load carrier is shifted from juxtacortical lateral to the medullary cavity. The nail has three notches. One notch is situated cranial in a diagonal direction; it runs from lateral distal to proximal medial, corresponding to the CCD angle, and it is used to insert the lag screw, spiral blade, or T-profile anchorage. Two distal notches enable the placement of interlocking screws that secure leg length and guarantee rotational stability of the implant in the femur. The components of the implant are inserted by precisely working target devices only using small stab incisions. While the load carrier of the head-neck fragment is dynamically mounted to the nail in order to allow compression onto the fracture, the nail itself can be locked distally using bicortical screws dynamically (with a sliding path of approximately 10 mm) or statically, with no play of the nail in the medullary cavity at all.

Experimental studies revealed that the load-bearing capacity is higher using intramedullary implants compared with extramedullary osteosynthesis, because the lever arm calculated from the tip of the implant for the head-neck fragment to the nail versus to the plate is shorter in the former. Furthermore, the load transfer to the femur shaft is distributed across a longer distance in a dynamic way. The compressing mechanism can occur in two directions simultaneously [6, 8, 10, 22, 24, 37, 44, 46, 50, 51, 56, 58, 61, 67, 74, 75]. Secondary dynamization, that is, removal of the distal locking screw, is hardly ever necessary and is only indicated if delayed union is suspected after observing a series of follow-up X-rays.

Workflow of the surgery:

- Positioning of the anesthetized patient on the traction table. Fixing both legs and bracing the pubic bone on the fracture side on a pillar padded with cotton wool
- Reduction of the fracture using longitudinal traction and rotation under image intensifiers control (a.p. and axial) in slight adduction of max.10°
- Determining the CCD angle and choosing the appropriate implant (from 120° to 140° in 5° intervals)
- Disinfection and sterile draping of the surgical field
- Skin incision a few centimeters cranial of the palpable tip of the trochanter. Splitting of the fasciae and musculature on the tip of the trochanter slightly oblique down to the medial side
- Opening the medullary cavity with a pointed awl and inserting the guide wire into the medullary cavity
- If necessary, enlarging the trochanteric region and medullary cavity by hand using a cannulated drill, which corresponds to the external dimension of the nail: largest diameter for the trochanteric region, smaller ones corresponding to the peripheral nail diameter for the medullary cavity.
- Manual insertion of the nail connected to the target device into the medullary cavity, using the inserted guide wire as guidance. It is possible to equip the target device with an aligner unit in order to facilitate the optimal positioning of the guide wire for the head-neck implant and for adjustment of the nail in both planes using image intensifiers.
- Second skin incision according to the target device, splitting of the fasciae and pushing away the musculature with a protective sleeve until the target device has contact to the bone
- Removal of the guide wire
- Opening of the lateral corticalis with the spiral drill. As a consequence, the guide wire for the head implant does not bend under manual pressure when the corticalis is opened, causing a diversion when the notch of the nail is passed. If this is not considered, the reamer in the next step collides with the wall of the nail, which can cause a vulnerable point for nail breakage.
- According to the designated length of the head screw, spiral blade, or T-profile anchorage, the implant is inserted according to the instruction manuals and, if necessary, secured by a set screw for the defined glide path [20, 39].
- Finally, distal locking is carried out, usually with a screw. The protective sleeve is used to ensure good bone contact without interposition of soft tissue. Drilling through both cortices, the necessary length of the screw is measured and the screw is inserted manually with the help of a screwdriver. The usage of a mallet is strictly forbidden.
- For combined fractures such as trochanteric fractures with a femoral shaft fracture, the use of a long Gamma nail is recommended [17].

Advantages and Disadvantages

In all its varieties, the intramedullary osteosynthesis is a closed, minimally invasive method. The alignment of the fracture fragments must be correct in all planes prior to stabilization. If closed reduction combined with percutaneous simple reposition aids is insufficient to achieve an acceptable result, open reduction should be performed to reach this goal as well as to restore length proportions [54].

Although it seems to be a technically simple surgical procedure, the surgeon has to be aware of possible sources of error, which come to be known with experience. The surgical steps are as follows:

- Reduction should be performed prior to the actual osteosynthesis.
- It is necessary to widen the medullary cavity as needed.
- The nail must be inserted manually. If it cannot be inserted without extreme force, it should be removed and the medullary cavity should be widened a little bit more. Under no circumstances should the nail be hammered into the medullary cavity. As a consequence, a fracture of the femoral shaft would occur on a regular basis.
- A backlash between the target device and the nail results in a loss of precision during the drilling procedure. This can cause mis-drilling. The connection between the two elements should be checked regularly during the surgery.
- Distal locking should be controlled using the image intensifier. If the targeting device misses the hole in the nail, locking should be performed using the so-called freehand technique. Generally, distal locking with a single bolt is sufficient. Two bolts are only necessary in really rare cases. This step must be performed without applying any force. Each crack in the bone and each mis- drill can be the source of an immediate or delayed fracture.

It is important that each layer of the wound for nail insertion is drained separately for 48 h. Especially in obese patients, there is a tendency of serous wound secretions lasting for days. Furthermore, the exit points of the drains are a source of lymph secretion. In these cases, it is advisable to look for hypoproteinemia and, if necessary, to treat it. Mobilization with weight bearing is generally possible. Full weight bearing supports the compression process of the fracture fragments and should be considered as a part of the treatment regime.

Cutting out of the screw is more likely in fractures with a short proximal main fragment and a medial defect (separate fragment of the lesser trochanter). Three factors abet a cutting through of the implant:

- Poor bone quality (osteoporosis)
- Malpositioning of the implant in the head-neck fragment
- Possibility of rotational movement of the proximal main bone fragment [11, 22, 24, 25, 31, 39]

This rotational movement can possibly be avoided by using an implant with a changed profile (spiral blade, T-profile). Furthermore, special aliform attachments (U-blade) can be combined with the head screw. They can be inserted into the indentations of the screw with the intention to spread their tips in the cancellous head fragment on two sides. Finally, they can be connected with the peripheral end of the screw.

In the past, insertion of two head screws without a security mechanism in the nail often led to lateral migration of the proximal head screw as well as to medial or lateral migration of the distal head screw (Z-effect) due to cyclic loading. (Some researchers suggest that the constant configuration with a right-handed thread used for both legs could lead to loosening in fractures located on the left side.)

Intramedullary nailing has proved its efficiency over the last 20 years. It should be considered as today's standard treatment for managing instable pertrochanteric fractures [12]. The postoperative treatment modalities follow the same rules as described in the chapter [19, 66].

Complications

Type of complication	%
Intraoperative fracture – Trochanter major	2.0–4.5
Intraoperative femur shaft fracture	0.2
Open reduction	0.5
Mis-drillings	3
Failure of targeting device	1.2
Rotational deformity	0.3
Hematoma – revision	0.5–5.0
Seroma	2.5–10.0
Infection (superficial)	0.3
Infection (deep)	1.7
Deep vein thrombosis	0.7
Cut-out	2.1–3.7
Avascular necrosis of the head	0.5
Early postoperative shaft fracture	0.3
Late postoperative shaft fracture	0.5
Nonunion, nail breakage	0.3–5.0
Mortality <12 months	18.6

Primary and Secondary Hip Arthoplasty

Only a few departments treat trochanteric fractures with a primary hip joint replacement on a routine basis. The justification for this approach is that a definitive single-stage procedure with a good anchorage of the implant in the osteoporotic bone should be the primary goal. However, the complication rates including postoperative hematoma that need surgical revision, superficial and deep infections, as well as a dislocation rate of up to 20 % indicate that the advantages cannot compensate the serious disadvantages. Endoprosthetic management should only be used in rare particular cases. The cemented technique must be preferred. Special attention should be devoted to reinsert the musculature thoroughly. The anchorage of the greater trochanter must be existent, whether by using a special osteosynthesis or by a technically well-performed tension band wiring [28, 57, 73].

Sometimes it is necessary to position the affected leg in an abduction pillow in combination with prolonged bed rest. Clear indications for the implantation of prosthesis are:

- Existence of a severe coxarthrosis with joint stiffness
- Osteosynthesis failure with low chances of a successful re-osteosynthesis
- Secondary development of a coxarthrosis or avascular necrosis of the femoral head

Advantages and Disadvantages

Primary hip arthroplasty is possible in patients with a severe coxarthrosis who are in good physical condition. It seems to be important that the surgeon has adequate experience with the implant technique, resulting in the best possible guarantee to avoid failures. In general, implanting a total- or hemi-prosthesis is more physically demanding. The burden and load connected to surgery and narcosis should be expressed.

Complications

Type of complication	%
Hematoma	2.0
Superficial infection	2.0
Deep infection	3.0
Dislocation	12.0
Mortality >12 months	34.0

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21 Femoral Shaft Fractures

Vilmos Vécsei

21.1 Definition

A femoral shaft fracture is a fracture of the femur diaphysis, which is located between two horizontal lines running proximally through the middle of the trochanter minor and distally 5 cm proximally of the tuberculum adductorium [16].

21.2 Etiology/Epidemiology

- Assuming regular bone structure, a femoral shaft fracture is caused by direct-impact, high-energy trauma.
- Indirect impact such as torsion trauma causes a femoral fracture more often in children than in adults.
- Repetitive microtrauma can cause a fatigue fracture.
- Bone metastases, primary bone tumors, metabolic diseases such as vitamin D deficiency and osteogenesis imperfect are the cause of pathological fractures. Fractures that do not correspond with the injury pattern are strongly suspected of being pathological fractures.

Assuming peacetime and a mean volume of traffic, 2,500–2,800 femoral shaft fractures are estimated out of a patient population of ten million Europeans. Up to 30 % of the femoral shaft fractures occur in polytraumatized patients and up to 15 % are accompanied by knee ligament or meniscal lesions.

21.2.1 Concomitant Injuries

- Blood loss, shock, circulatory instability

  Generally, blood loss of 1,000–1,500 ml has to be assumed in femoral shaft fractures. In up to 40 % of the injured patients it is indicated to administer blood transfusions preoperatively due to the evaluated symptoms and lab results.
- Local bleeding, compartment syndrome

  The painful hardening of muscle compartments is an indication to measure the compartment pressure. Peripheral dys-/paresthesia can be an indirect indicator of a compartment syndrome.
- Fat embolism, adult respiratory distress syndrome (ARDS)

  Movement of the fracture fragments, muscle tensioning to prevent pain, and local increase of pressure provoke migration of medullary cavity contents through the venous sinusoids into the central venous circulatory system, causing embolisms. Through the right ventricle of the heart, the embolisms are thrown into the pulmonary circulation, where they are filtered and intercepted in the capillaries according to their corresponding size. This process can take place unnoticed or, depending on the massiveness of the migrated content and the current circulatory situation, it can lead to a fat embolism syndrome that restricts the gas exchange in the lung [1, 11]

  Vascular injury, a. and/or v. femoralis superficialis
- Nerve paralysis, peroneal palsy, ischiadicus palsy
- Increased danger of infection for soft tissue and bone after serious soft tissue damage, especially in open fractures [2, 9]

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21.3 Diagnostics

21.3.1 Symptoms

- Painful loading incapacity of the affected leg, axis deviation, swelling, leg shortening and deformity, motor weakness up to the inability to lift the leg from the ground
- In case of open fractures, damage of the soft tissue in combination with blood loss through the wounds

Depending on the amount of blood loss, mild to more pronounced symptoms of hemorrhagic shock: paleness, restlessness, acrocyanosis, puffed eyes, racing pulse, reduction of the systolic blood pressure

21.3.2 Clinical Examination

In the majority of cases, the femoral shaft fracture is an instant clinical diagnosis. Thorough clinical examination is necessary to confirm that there are no concomitant injuries. The following steps must be performed regularly and should be documented:

- Foot pulses: a. dorsalis pedis and tibialis posterior and, if necessary, a Doppler sonography that shows the pressure gradient
- Peripheral sensibility and motor function
- Inspection and palpation of the pelvis, hip joint, lower leg, ankle, and forefoot under the assumption that a femur fracture is caused by massive violence that can provoke other injuries to the same extremity and to the pelvis
- Stability examination, especially of the knee joint, can only be performed reliably when the femur fracture has been stabilized. This is an obligatory part of the treatment strategy. A diagnostic arthroscopy is not justified as a tool of verification. However, an MRI assessment could be considered necessary postoperatively. This factor should be taken into account while choosing the adequate implant for fracture stabilization.

21.3.3 Imaging Methods

Conventional X-rays in two planes

For accurate assessment of the fracture, the entire femur should be imaged to detect any accompanying injuries of the femoral neck, the trochanteric area, or the supracondylar area. In case of doubt, a specific X-ray of the hip and knee joint should be performed, if it is needed for decision making. Images of bad or poor quality may not be accepted.

21.3.3.1 Computed tomography (CT)

CT can be used to verify fracture courses, for example, of a concomitant femoral neck fracture, which are not or not clearly seen on the native X-rays. Generally, in order to clarify a femoral shaft fracture a CT scan is not indicated; furthermore it is absolutely not obligatory.

21.3.3.2 Angio CT

If a vascular stem lesion is suspected, for example, in the absence of a foot pulse, the vascular course has to be displayed and documented. In ballistic fractures this step should be considered a priority.

21.3.3.3 Angiography

A digital subtraction angiography (DSA) can be used to verify vascular injuries. It provides more detailed information about bypass circulation, collateral vascular supply and connections, and so on, which could be of surgical technical interest.

21.3.3.4 Phlebography

Phlebography is indicated if inexplicable swelling is observed. It must be performed in order to exclude venous vascular stem lesions or obstructions.

21.4 Classification

Of the classification systems for shaft fractures, respectively, for the concomitant soft tissue damage referring to closed and to open fractures, the OTA [17] or the AO [16] system is accepted. Fracture types can be classified into subgroups enabling a comparison of different treatment modalities and of their outcome. Number three has been assigned to the femur. After virtual removal of the parts near the hip joint and of the condylar area, the diaphysis of the femur can be divided into three equal segments. As a result, the whole femur is composed of five sections. The diaphysis consists of the segments 3, 4, and 5 in a cranio-caudal direction. The numeral 33 means that the main part of the fracture is located in the proximal third of the diaphysis, whereas 34 refers to the middle and 35 to the distal third. The degree of severity is expressed by the characters A, B, and C. A indicates a simple fracture, whereas C represents a complex fracture. Each of these can be subdivided into three types, which are characterized by the numbers 1, 2, and 3.

- Type A: simple fracture; A1 spiral, A2 oblique (more than 30°), A3 transverse (less than 30° measured to the longitudinal axis of the femur diaphysis)
- Type B: wedge fracture; B1 spiral, B2 bending, B3 fragmented
- Type C: complex fracture; C1 spiral, C2 segmental, C3 irregular

For example, 33 A3 can be interpreted as a multiple fragmented comminuted fracture in the middle of the diaphysis. C 1–4 and O 1–4 can be expressed as closed (C) or open (O) tissue damage.

Fundamentally, a subtrochanteric fracture is classified as a proximal femoral shaft fracture as long as the main part of the fracture is located distally to a horizontal line through the middle of the trochanter minor. On the other hand, if the main part of the fracture is proximal to this virtual line, these fractures have to be classified as trochanteric fractures. Therefore, it may be deduced that a subtrochanteric fracture can have an extension into the trochanteric region.

A supracondylar fracture is classified as a shaft fracture, if the main part of the fracture lies proximal to a square, which is placed over the part of the femur near to the knee joint and whose side length corresponds to the largest diameter of the distal femur. The fracture can have an extension into the joint, which is usually not displaced.

21.5 Treatment

We noticed an accumulation of these fractures in children between the ages of 2 to 5 years, mostly as the result of simple falls with rotary mechanism. Between the ages of 18 and 45 years, femoral shaft fractures are caused by motor vehicle accidents (mainly men are affected), whereas between the ages of 70 and 85 years women are victims of simple falls at home. Due to this inhomogeneous patient population, guidelines referring to treatment modalities and to day of surgery cannot be considered applicable in general to all age groups without turning the exception into the rule.

The choice of treatment for a femoral shaft fracture depends on age and general health status, which should be assessed by:

- Respiratory rate
- Gas exchange
- Pulse rate
- Blood pressure
- Urine production per hour
- Required ventilator support
- Needs of fluids and medication for sustaining circulation
- Anamnestic evaluation (former illness and special medication, e.g. hypocoagulation, anticoagulation, cardiac circulatory diseases, malignant neoplasm diseases, etc.)

The method of choice for the treatment of femur fractures is conservative in small children, initial intramedullary osteosynthesis in middle aged patients, and (after clearance for surgery by internal medicine) secondary operative treatment 2 or 3 days after trauma in elderly patients.

If an initial operative treatment of the fracture is the foal, the surgery should not start earlier than 2 or 3 h after admission or diagnosis, with an adequate observational period. Only in case of severe acute pathologies like open fractures with vascular injuries is immediate intervention mandatory. Many of the injured patients who are suited for primary surgery benefit from an early definitive treatment for the following reasons:

- Reduction of the painful period caused by the fracture itself
- Reduction of complications, such as respiratory gas exchange disorders, pneumonia, decubital ulcers, urinary tract infection, etc.

Preconditions for setting up the time point of surgical stabilization of the fracture are:

- Regular gas exchange (Horowitz index, arterial blood gas analysis, normopnoea)
- Urine production of 50 ml/h for at least 2 h
- Pulse rate lower than 100/min
- Systolic blood pressure higher than 100 mmHg
- No need of catecholamines
- Clotting scores and a platelet count of more than 200,000/mm^3
- Hemoglobin level above 11 g%, hematocrit level above 30 %

In the case that surgical intervention must be postponed, the conservative regimen should start in the same way as if complete conservative treatment was intended. This principle must be carried out, although it is known from experience that conservative treatment of a femoral shaft fracture is only completed in rare cases. Sometimes the first treatment remains the definitive one. If surgery is planned in the next few days, no axis deviation can be tolerated because it may not be possible to eradicate it, in case that the surgery was postponed for too long. Therefore, each therapeutic step should be carried out as if it is the last and definitive one.

21.5.1 Conservative Treatment

Indications for conservative treatment are:

- Fractures in children (preschool)
- Current and definitely inoperable fractures in adults
- Initial treatment during preparation for surgery

Several types of conservative treatment are available [6].

21.5.1.1 Plaster Cast

Plaster cast is appropriate for the treatment of undisplaced or minimally displaced fractures without shortening. To immobilize adjacent joints, it is essential to treat the femoral shaft fracture with a pelvic-leg plaster cast. Depending on whether the fracture is located very proximally or distally, the foot respective of the pelvic part can be omitted. Principally, no concessions should be made referring to the length of the cast, especially at the beginning of the treatment.

- The plaster cast should be controlled on a regular basis; it must be renewed every 4 weeks or if it is damaged.

The purpose of a plaster cast is to support the soft tissues in order to relieve the fracture site. Because that secondary axis deviation is possible using the plaster cast, it is beneficial to start traction treatment until the fracture has bonded and to change to the pelvic-leg cast afterwards in order to achieve earlier mobilization. The duration of fixation in adults is 12–14 weeks. After this time period, the healing rate of the fracture lies between 90 and 95 %.

The disadvantage of treatment with a plaster cast is that secondary axis deviation or shortening cannot be prevented definitively, as explained above. In consequence, the domain of plaster casting is a fracture that is located in the distal third of the shaft and that is not or just minimally displaced, without any or with only minimal tendencies for displacement or shortening.

21.5.1.2 Traction Treatment

Buck's traction is an apparatus for applying longitudinal traction on the leg by contact between the skin and the adhesive tape, to maintain the proper alignment of a leg fracture. Friction between tape and skin permits application of force through a cord over a pulley with a suspended weight. The advantage of this treatment is that no invasive steps are needed for effective application of the traction weights. The disadvantage is that traction weights that are sufficiently heavy for femoral shaft fractures cannot be fixed. Skin irritations, tension blisters, and skin necrosis may develop under the adhesive tape or the traction may loosen and thus ruin the treatment. As a consequence, Buck's traction is not appropriate for the treatment of femoral shaft fractures in adults, even on a temporary basis. The risk of damage is greater than any possible benefits.

Nevertheless, Buck's traction – especially the method of Bardenheuer – has proven its worth in successfully treating femoral shaft fractures in small children (Fig. 21.1). After confirmation of the diagnosis by X-ray, the procedure should be performed as follows:

- Both legs are undressed. The skin is cleaned and degreased with disinfectant or ether.
- Adhesive tape, in which a small wooden plate is integrated into the pull cord, is trimmed to size laterally and medially and then the protective foil is removed. The adhesive tape is placed laterally and medially in a way that the wooden plate lies 2–3 cm away from the heel. The skin of the distal part of the femur and the whole lower leg should be covered, leaving strips of skin uncovered at the front and back.
- The same procedure is then applied symmetrically onto the contralateral side.
- The adhesive tapes are covered with elastic bandages from the ankle upwards.
- Afterwards, the pull cords (which are integrated into the heel plate and attached to rollers that are suspended over the bed on crossbeams) are weighted symmetrically with traction weights of 1–3 kg, depending on the weight of the child. The position is correct if the child's buttocks are raised from the bed so that an adult's flat hand can slide in between the sheet and the child's bottom (most children are still in diapers).

Fig. 21.1 Small child with femoral shaft fracture in Bardenheuer traction

- One hour after applying the adhesive tapes, an X-ray control in two planes should be performed; necessary adjustments of the traction weight are made.
- Two or three days after the traction apparatus has been applied, the children are free of pain and have lost all shyness. They start to turn around the axis of their suspended legs. As their toys and books are usually placed on the bedside table, they tend to move into this direction. Additionally, the child's parent or another caregiver normally stands on the same side because it is easier to pass on the toys. At least on the second of the weekly X-ray controls a varus or valgus malposition in the direction of the bedside table can be observed. By changing the bedside table to the other side, an axis correction can be achieved automatically.
- The traction weights are adjusted according to the X-ray controls. Distraction of the fragments should be strictly avoided.
- The duration of the traction treatment depends on age and size. It ends after 3–6 weeks when radiographic images show bridging callous.
- Should the adhesive tapes loosen, they must be exchanged immediately. If this is not possible due to skin intolerance, a K-wire should be applied through the distal tibia, which is equipped with a Beck's spring clip, in order to continue the traction treatment. This intervention is rare.
- After expiration of the traction treatment period, the adhesive tapes are removed and skin care is carried out if necessary.
- An active mobilization is not required as children start sitting and standing up in bed within 2–3 days.
- For pathological fractures referring to osteogenesis imperfect, the traction treatment period should be extended by one-third.
- In a few rare cases it is necessary to apply a plaster cast after removing the adhesive tapes, for example, if the X-rays verify a secondary deflection due to the insufficient maturity of the callus.
- Following these guidelines, the rate of bone healing is almost 100 %.

The only disadvantages of applying Buck's traction treatment in young children are the length of time and the fact that special equipment is needed. In our department, the treatment is performed on an inpatient basis, whereas in some parts of the Netherlands the children are sent home after 2–3 days. A bed is borrowed from the hospital and controls are carried out by local doctors. Though might be suspected that this treatment is not up-to-date and that the child is impeded causing retardation, the presence and attention of the parents and of other relatives as well as the permanent preoccupation with the child during the treatment result in a phenomenal development boost. Furthermore, psychological damage in terms of hospital trauma has not been detected. If these children are compared to ones who underwent surgery (who are discharged from hospital after a shorter time period and therefore are not attended in such a meticulous way), they do not suffer from anxiety and psychological damage.

Skeletal Traction

Greater traction weights, which are necessary for axis or length corrections, must be applied directly on the bone and not on the soft tissue. In order to manipulate the broken bone, local "fracture gap" anesthesia or general anesthesia is needed [6]. The local anesthesia into the fracture gap is performed under sterile precautions after surgical disinfection of the assumed fracture area. After placing a cutaneous depot, 10–15 ml of a 1 % procain solution or equivalent is injected into the fracture gap. By aspirating fracture hematoma it is proven that the tip of the needle is in the fracture gap. One minute later, pain-free manipulation is possible for 60–90 min. The traction apparatus is also mounted under local anesthesia. The area of the proximal tibia or distal femur is disinfected and the planned entry and exit point of the Kirschner wire or the Steinmann pin are injected with a 1 % solution of local anesthetic. After placing a cutaneous wheal, periosteum and bone can be approached while constantly injecting the anesthetic. Particular attention should be paid to the periosteum; pain is avoided by setting a medial and a lateral periosteum depot. The necessary amount of local anesthetic for the proximal tibia is approximately 10 (2 × 5) ml and for the distal femur 20 (2 × 10) ml at most. Prior to disinfection and local anesthesia, the pain-free leg (due to the fracture gap anesthesia) is positioned and manipulated in a way that the assembly of the traction apparatus is possible without any interference. Basically, there are two different types of traction assemblies, the Kirschner wire traction and the Steinmann pin traction.

Kirschner Wire Traction

After disinfection and draping, a sterile drilling machine is used to insert a 1.6-mm Kirschner wire into the bone in a horizontal direction and perpendicular to the axis of the extremity. When the wire has been removed from the drilling machine, it is fixed to a spring clip using a tensioning chuck in order to condition the wire in a way that it can take greater loads and traction weights. Before the frame is installed, the wire entry and exit points are equipped with sterile felt patches and pelottes. The purpose of this measure is immediate wound care and infection prevention on the one hand and, on the other hand (which is more important), protection of sideways displacement and prevention of wire sliding, which – due to its connection to the frame – loosens in the bone with each rotational movement. We use the Kirschner wire traction temporarily for a short duration in adults preoperatively and routinely in children. The frames have a number of holes, where the pull cord for the traction can be anchored. They differ by size depending on the aspired localization (calcaneus, tibia, supracondylar).

Steinmann Pin Traction

The length and the diameter of the pins as well as the size of the frames are determined according to the affected area. The specific diameters can take up weight of up to one-seventh of the body weight without bending inside or outside of the bone. After disinfection, local anesthesia and surgical draping, the chosen pin should be driven into the bone under sterile conditions using a mallet of 0.5 kg weight from the medial to the lateral side, parallel to the frontal plane and perpendicular to the axis of the extremity, achieving central placement. As a result of "material displacement," the pin sticks in the bone. The corresponding frame is built in a way that it has a mobile connection to the pin through a connecting wheel. As a consequence, the nail does not move when the position of the leg is changed. This construction feature is crucial for preventing loosening and local infection. Furthermore, it is appropriate for traction assemblies that are prescribed for several months. Because of the risk of injury caused by the very sharp nail tip, it has to be covered with a protective cap on the lateral side after the nail has been connected to the frame. In the case of porous bone structure, it is further recommended to use felt padding and metal pelottes, which can also be applied subsequently in the course of traction treatment.

Tibial Head Traction

The Kirschner wire or Steinmann pin is inserted 2–3 cm dorsally (on the same level) of the tuberositas tibiae. Afterwards, the frame is mounted. The leg is placed on a Böhler-Braun splint; it has an angle of 60°

at the level of the knee joint. The pull cord is attached to rollers, which are mounted onto the bed crossbeams at whatever height is needed, in a way that the direction of traction can be adjusted into the position in which the proximal shaft fragment points. To relieve the knee joint, the traction weight is restricted to a maximum of 5 kg. The tibial head traction should be chosen in the preoperative phase as provisional treatment of a femur fracture, especially to correct shortening or to prevent it. On the one hand, this traction serves to relieve pain; on the other hand, the canal of the Steinmann pin or of the Kirschner wire should be regarded as potentially infected after a few days. In case of a secondary osteosynthesis of the femur, it is advantageous to avoid such a possible source of infection. If the definite conservative treatment method is intended (after 5–10 days the length proportions have been largely restored), it can be changed to a supracondylar traction in order to be able to attach traction weights of one-tenth of the body weight. Additionally, this change serves to relieve the knee joint and should prevent painful joint stiffening.

A capsule-ligament-lesion of the knee joint can be concomitant to a femoral shaft fracture. In such cases, it is better to refrain from tibial head traction, especially if there is instability in varus or valgus direction.

Supracondylar Femoral Traction [6]

In adults, the Kirschner wire or the Steinmann pin is placed in the distal metaphysis to enable a better manipulation of the fragments. The optimal position is 5 cm dorsally from the upper patella pole. If the Steinmann pin is placed too proximally, longitudinal fissures can result along the femoral diaphysis and, in the worst case, an iatrogenic supracondylar fracture can occur. Additionally, if the pin is placed too dorsally or if it is guided obliquely it could hit the adductor canal. Therefore, the assembly of a correct supracondylar traction (which can provoke significant complications) is an important task. Compared with the insertion of a Steinmann pin, the potential danger of placing a Kirschner wire is negligible. Surgeons who are not sufficiently experienced in this technique should absolutely use auxiliary devices to choose the correct point. One possibility is to place a K-wire or a pin on the upper patella pole and to take an X-ray. If the X-ray shadow of the object is in the correct position in the a.p. view, the next step is to determine the correct entry point in the lateral view. Applying this technique, a too proximal or too dorsal positioning is not possible. Furthermore, the use of an image intensifier is recommended, especially when using a Steinmann pin. The advantages of this traction type have already been mentioned.

Primary, supracondylar traction is applied if the femoral shaft fracture is accompanied by ligamentous knee injuries or if the use of traction is planned as a definitive treatment of an undisplaced fracture without shortening. Should there be obvious shortening of the soft tissue, the K-wire is placed higher in the region of the soft tissue than in the bone. As a consequence, after the traction is mounted, the soft tissues (skin, subcutis, fascia) are pulled very slowly, millimeter by millimeter (sometimes up to a few centimeters) distally, causing the moving K-wire to cut through them until their corresponding position to the bone is reached. Inevitably, this leads to secretion and infection of the soft tissue, which can spread to the bone and can quickly lead to a loosening of the hardware in the bone. This can be prevented if the initial shortening is primarily neutralized with the help of tibial head traction; when the length has adjusted, one can change to supracondylar traction.

The leg is placed onto a Böhler-Braun splint. Afterwards, by the respective frame, the distal fragment is pulled, in the same manner as described above, into the direction in which the proximal fragment is pointing. The foot as well as the head of the bed must be raised considerably in order to avoid low positioning of the patient's head. The healthy leg should be supported on a footboard. Only under these circumstances can it be guaranteed that the body weight acts as a counter balance, with the result that the patient is not pulled off the bed by the traction weights. The traction equipment, the position of the splint, the leg, the rotational setting, the function of the guide pulley, and the position of the traction weights have to be controlled at least once or twice daily. The position of the fracture has to be documented by X-ray images in two planes after the first and the second day and then once a week. Any necessary changes (direction of traction, reduction of the traction weights) can be evaluated from the X-ray images. After changes have been made, even after insertion of a pillow onto the splint, X-rays always should be performed 24 h later. Distraction of the fragments should be avoided under any circumstances.

The duration of the traction treatment in adults is 12 weeks until the femur fracture has healed. With the respective care, callous fracture healing without axis deviation can be obtained in up to 97 % of patients. The traction assembly should be kept in place during the whole healing process. If the time is shortened to a 6- to 8-week duration of traction treatment followed by plaster cast immobilization, the pelvis-leg plaster cast is not in the position to prevent any secondary distortions of the bone (which is still soft) due to the thickness of the thigh musculature. This type of change in the treatment modality should only be performed if the traction treatment has to be abandoned [6]. Of course, irreparable loosening of the supracondylar Steinman pin is not necessarily such an indication. In these cases, depending on the remaining duration of the traction period, the pin should be removed and re-positioned into the tibial head for a short time period until the wound has healed. Afterwards, the position can be changed again, applying new supracondylar traction.

The following points are essential over the entire treatment period:

- Active decubitus prophylaxis
- Respiratory exercises
- Exercises for all uninjured extremities, especially for the healthy leg (exercises against resistance on the oblique surface)
- Thrombosis prophylaxis with low molecular heparin or, in case of additional risk factors, coumarin therapy

The conservative therapy is time-consuming and work-intensive. Generally, mistakes are possible that are not always correctable after time has elapsed. Special splints and suspension modalities may be needed for special cases, such as the 90–90° traction, in which the hip and the knee joint must be held in a 90° flexed position and the lower leg is balanced separately by a pulley. This assembly is necessary in cases of subtrochanteric fractures or open fractures, where a complication wound is located in the area of the buttocks or on the flexion side of the femur. Having nursed the wound carefully, it is possible to return to the standard traction treatment to keep the position of the joint as close as possible to the so-called "middle position."

21.5.2 Surgical Treatment

The treatment of choice or standard therapy for subtrochanteric femur shaft fractures and supracondylar fractures is surgical treatment (osteosynthesis). The surgical assembly of the pieces of bone can be carried out in an open, semi-open, or covered procedure.

21.5.2.1 Open Reduction

The *standard approach to the femur* starting at the trochanter down to the condylar area is the posterior-lateral approach. As an alternative, the lateral approach between m. vastus lateralis and intermedius can be used. The incision is made in the middle of the lateral contour of the femur in the connection line between the tip of the trochanter and the middle of the lateral aspect of the lateral femoral condyle. After splitting of the subcutis, the fascia lata becomes visible. It is incised and split with a pair of scissors in the direction of the fibers. The m. vastus lateralis is now exposed. On the dorsal edge of the muscle, the septum intermusculare laterale can be reached. The musculature on the septum is mobilized and pushed aside with a raspatory, whereby the pairs of vessels (arteria and vena) that perforate the septum are dissected and clipped on each side and subsequently ligated. The stumps lying towards the septum should be handled especially carefully and kept a little bit longer. If the vessel stumps are not ligated and slip behind the septum, this can lead to profuse bleeding. After performing the ligatures, the muscle can easily be detached from the septum and the femur. If necessary, for example, in subtrochanteric fractures, the origin of the muscle can be taken off diagonally after attaching retention stitches, so that the whole lateral aspect of the femur can be portrayed. After the fracture has been reduced and stabilized, the muscle can slip back into its normal position. If necessary, a drain can be placed in the muscle compartment followed by the closure of the fascia using single knotted stitches and absorbable suture material. A subcutaneous drain may be placed and the skin is closed. As part of the dressing change after 48 h, the drain is also removed. We do not cover the wounds after the fifth postoperative day, if healing is regular. Finally, the stitches are removed on the 12th postoperative day.

21.5.2.2 Closed Reduction

As long as femur fractures can be classified as "recent," they can be regularly reduced into a correct axis on the *traction table* by supporting the pubic bone and applying a longitudinal traction. Fractures, in which the musculature is interposed in the fragments and therefore hinder sthe union of the fracture surfaces, cannot be included under this rule. These interpositions must be removed by opening the fracture site. Depending on the individual case, it must be decided whether to continue with an open approach or, after removal of the interposition, to continue with an exactly performed reduction according to the minimally invasive technique so as to finish the surgery appropriately using the chosen method and implant. The patient can be placed in a supine or lateral decubitus position on the traction table. In general, the rotational conditions between the proximal and the distal fragment can be better evaluated when the patient is in a supine position. To achieve accurate closed reduction, the Müller distractor can be used as well. Its threaded pins should be placed proximally and distally close to the dorsal corticalis, where they find a good hold and neither impede the pathway of the intramedullary nor of the juxtacortical implant. With the distractor's threaded bar and the possibility to tilt one of the main fragments, an accurate reduction can be achieved after distraction of the fracture. If a Müller distractor is not available, it can be imitated by a regular external fixator.

According to fracture location and type, various implants which are adapted to the relevant part of the femur and able to bear the equivalent load, are used for stabilization while the bone is healing.

21.5.2.3 Intramedullary Osteosynthesis

Intramedullary Nailing (Küntscher [13–15])

Principle: This is based on elastic deadlock of a slotted load-bearing carrier with a cloverleaf profile by a longitudinal deformation in the medullary cavity. The nail should splint the fracture both proximally and distally at a minimum of 3 cm or even better of 5 cm length in order to achieve a tube-in-tube stabilization. The bony tube on both sites of the fracture has to be intact. Rotational stability is achieved by interlocking of the fracture surfaces. Weight transfer is possible through the implant and the restored bone. Closed reduction, without opening of the fracture site, has the advantage of lower infection rate, earlier weight bearing, and a reduced risk of scarring of the muscle with the bone due to the small wound.

Indication: Transverse and short oblique fractures, pseudarthrosis (nonunions) in the middle third of the shaft

Necessary Instruments, Tools, and Implants:

- Traction table or Müller distractor
- One to two image intensifiers
- Medullary cavity reamer, mechanically or manually driven
- Guide wire for the reamer and the intramedullary nail
- Instruments for insertion and removal of the nail
- A complete set of nails (diameter: 10–20 mm, length: 34–48 cm, length difference: 1 cm)

Technique: The patient is placed on the traction table in a supine or lateral position. Closed reduction of the fracture is performed. Alternatively, the Müller distractor is applied to reduce the fracture. Skin incision is made at the palpable tip of the trochanter major in a caudo-cranial direction. The fascia and the gluteal muscles are split in fiber direction in a length of 5 cm. The medullary cavity is opened with the curved pointed awl. A guide wire is inserted into the medullary cavity of both main fragments. The medullary canal is reamed through the guide wire with the cannulated medullary cavity reamer, starting with the 9 mm drill. Afterwards, the medullary cavity is reamed step-by-step, using drill bits with increasing diameter (0.5 mm) until the drill grips in both of the main fragments. These steps should be performed with the highest possible revolution speed of the reamer and by passing the medullary cavity as slowly as possible, in order to produce the lowest possible pressure increase in the medullary cavity and the lowest possible heat generation [1]. The reamer guide is changed for the guide wire of the nail, which is pushed into the center of the medullary cavity. The peripheral end of the guide wire should be placed in the middle of the distal femur metaphysis 1 cm proximal of the joint surface (proximal of the incisura intercondyloidea) to offer optimal axis guidance for the intramedullary nail. The length of the chosen nail results from the difference of the length of the guide wire, positioned in the medullary cavity, and the one that protrudes from the trochanter major. The chosen diameter should be 1 mm smaller than the diameter of the reamer head that was used at the end. (As a Central European benchmark for adults, the following factors for a body height of 170–175 cm can be expected: reaming of the medullary cavity 15 mm, measurements of the nail most frequently used: length 40 cm with a diameter of 14 mm. Of course, the length and diameter vary according to the body height and race.) The nail is inserted into the medullary cavity through the guide wire using light hammer blows. If the chosen length is correct, the proximal end of the nail will be even with the tip of the trochanter major, and the tip of the nail will lie 1 cm proximal to the joint surface in order to prevent fissures of the cartilage surface in the intercondylar area. If the distal distance is too small, the development of a postoperative hemarthros and, in the longer run, of a femoropatellar arthrosis can be the consequence. Therefore, properly performed X-rays in two planes should be taken before the surgery is finished. The soft tissue wound is closed with absorbable stitches. It is advisable to insert one drain to the proximal tip of the nail and one subcutaneously.

Postoperative treatment: The dressing is changed after 48 h and the drains are removed at the same time. The stitches are removed after 12 days postoperatively. Weight bearing of the affected leg is allowed as tolerated due to pain. If the indication for intramedullary nailing was appropriate and if the surgery was performed accurately, all mechanical requirements for full-weight bearing are met immediately after surgery. One week postoperatively and then after 4, 8, 12, and 24 weeks, X-rays are taken to document the healing progress. Finally, the nail can be removed 18–24 months postoperatively.

Advantages: Intramedullary nailing according to Küntscher is a closed reduction osteosynthesis procedure without opening the fracture site. As a consequence, a low rate of infection (2 %) with low morbidity and a high rate of bony healing can be expected [10]. A further advantage is the fact that early full-weight bearing of the treated leg is possible.

Disadvantages and complications: If the fracture surfaces do not interlock, distinct reaming of the medullary cavity provokes increasing rotational instability. Therefore, distraction at the fracture site should be strictly avoided. Reaming of the medullary cavity causes an intramedullary pressure increase, which provokes an inflow of medullary contents and fat into the venous outlet system and can lead to embolization in the pulmonary circulatory system (fat embolism syndrome) [18]. Nutritive vascular canals in the endosteum can be occluded. A further consequence is the devascularization of the endosteum and a blood circulation disorder of the bone. Through the periostal blood supply there is a centripetal compensation of the perfusion. After reaming, the periostal blood supply is raised manifold. Six to eight weeks are needed to restore the endostal blood supply, depending on the damaged length. This process can be delayed or stopped because of excessive heat development during the reaming procedure (heat necrosis), resulting in sequestration. Resorption processes, especially in combination with infection (with typical clinical signs like fever, chills, reddening, and fistulas) can spread to the entire medullary cavity and can cause loosening of the nail. This complication is called medullary phlegmona and can provoke a life-threatening septic reaction. First, the complex context must first be recognized. Only experience and consultation enable an adequate reaction, which should result in a treatment plan (delayed healing of the fracture, pseudarthrosis, sepsis, septic pseudarthrosis, segmental defect, and defect nonunion).

If the medullary cavity is not accurately prepared by reaming or if the diameter of the nail is too large, the nail can get stuck. Driving the nail into the bone using excessive force can lead to further fragmentation and to avulsion of the femoral neck. As a consequence, the nail has to be removed. The medullary cavity must be re-prepared properly or the diameter of the nail has to be reduced. Only in rare cases does the nail break; in general, this problem can be solved by re-nailing after further reaming and by the use of a nail with a larger diameter.

If the nail is inserted too medially, for example, in the fossa piriformis, the branches of the a. circumflexa femoris lateralis, which are responsible for the blood supply of the femoral head, can be interrupted. After a certain time period a consecutive avascular femoral head necrosis (AVN) can develop.

Surgery is performed with the help of image intensifiers. Although the radiation exposure of the patient is negligible, the level of radioactive contamination of the surgical team must be controlled.

The classical indication for intramedullary nailing combined with reaming is restricted to transverse and short oblique fractures, which are located in the middle part of the shaft and is therefore very narrow.

These principles can also be realized with a slotted, clover-leaf profile nail using a basic set for interlocking nails. Solid nails and nails without a slot are not suitable for classical intramedullary nailing. They can only be used for "pinning" of the fracture. With these implants it is not possible to achieve a diagonal deadlock in combination with a longitudinal deformation.

Healing rate: 96 %.

21.5.2.4 Interlocking Nailing

Principle [12, 15]: The logical extension of intramedullary nailing in the terms of length, axis, and rotational control is an implant bone compound, transfixing the nail in the bone cylinder with the help of interlocking screws. To prevent a tilting motion of the implant (in case the nail is smaller than the diameter of the medullary cavity), a traversing bolt (screw) should be inserted at an oblique angle to the nail axis. However, if interlocking is performed perpendicular to the nail, double interlocking (two screws, double transfixation) is necessary to prevent a tilting motion, as mentioned above. Interlocking enables use of nails with smaller diameters compared to the medullary cavity because intimate contact between the inner surface of the medullary cavity and the surface of the nail (tube-in-tube stabilization) is no longer crucial for stable intramedullary osteosynthesis. Therefore, strictly speaking, the term “interlocking nailing” can only be used under specific circumstances. Actually, the term “interlocking splinting” according to Küntscher would be more appropriate.

Dynamic interlocking nailing: This is an adequate technique if the length of one of the main bony fragments is long enough that, after reaming, the nail becomes jammed transversally in this fragment. The second main fragment is too short and the width of its medullary cavity is too large. Therefore, to avoid any unwanted, disturbing rotational or tilting movements, this fragment is connected to the nail with an interlocking screw/bolt. Because the interlocking was only performed on one side, the weight that is put on the affected leg leads to an impaction of the fracture or to pseudarthrosis. As a consequence, the necessary local compression for bone healing will be generated. Dynamic interlocking nailing is therefore “real” medullary nailing combined with interlocking and it is used in fractures and pseudarthrosis, which are located proximal or distal of the narrowest part of the hourglass-shaped medullary cavity of the femur. Comminuted fractures (with several fracture fragments) or fractures that tend to shorten or are at risk of twisting are not suitable for treatment with the dynamic interlocking nailing method. Therefore, the best indications are pseudarthrosis and simple transverse or short oblique fractures. The nail-bone-union takes up the load, but the bone cylinder plays a decisive role as a load carrier as well.

Static interlocking nailing: If interlocking bolts are applied proximally and distally to the nail, the length and axis control is taken over by the statically interlocked nail (assuming that both bone fragments have an adequate length to be able to place the interlocking bolts). The load carrier is almost solely the nail, which transfers the load from the bolt proximally to the bone distally. Therefore, a nail is needed that offers the adequate load transmission capacity and possesses drill holes proximally and distally to incorporate the interlocking bolts. The bending capacity of a slotted medullary nail increases fourfold with every millimeter of increasing diameter. Further reinforcement results from the increase of the metal wall thickness in nails with large diameter. Another measure would be to eliminate the slot in the nail or ultimately the nail cavity as well. The result is a so-called solid nail. The increase in the nail’s mechanical attributes leads to a relative weakening of the bolts. Thin and weak bolts break before the nail breaks. Strengthening of the bolts and the nail leads to a cutting through mechanism and loosening of the bolts in mechanically weak bones (e.g., osteoporosis). Furthermore, the solid nail cannot be inserted with the help of a guide wire, which can lead to manipulation problems intraoperatively with regard to the optimal positioning of the nail. As a consequence, an axis deviation may occur.

These considerations are the reason for a discussion about implants of different manufacturers and about pros and cons of reaming. The optimal implant is cannulated, is only inserted temporarily, is not too stiff, has an antecurvature, and features a left and right version.

Proximal interlocking is performed percutaneously with the help of precisely working targeting devices, while distal interlocking is carried out in an orthograde radiation direction with the help of an image intensifier in the so-called “freehand technique.” From a mechanical point of view, the area of the femoral shaft, which lies between the two bolts, is an unburdened area. The first adopters of the interlocking nailing technique according to Küntscher feared that this zone would be revoked from the remodeling process (because it is mechanically neutralized) and will result in a too-weak bony structure that could be responsible for spontaneous fractures after implant removal. Therefore, they incorporated a dynamization into the treatment concept.

Dynamization means removing the interlocking bolt from the longer bone fragment after the first signs of callous consolidation have been detected at the fracture site by X-ray. The authors initially postulated that this step had to be performed 8 weeks postoperatively. In the course of time, it could be shown that this measure is unnecessary in the majority of the cases. After having removed the implant correctly, no re-fracture was observed after 1 1/2–2 years. Therefore, the theory of high stress protection can be dismissed. At present, dynamization is reserved for cases with delayed fracture healing verified by X-ray after a static interlocked procedure was performed. Furthermore, it is only expedient if the nail's dimensions are adequate to protect the axis and length of the femur and if a dynamic load can be placed onto the fracture zone. Dynamization can lead to healing, but it can also be the cause of complications (if performed improperly), which are shortening, axis deviation, and nonunion (especially if the bolt has been removed at the wrong time point and from the shorter fragment).

Indication for Interlocking Nailing:

- All types of fractures situated between the second and fourth fifth of the femur diaphysis (Fig. 21.2). In open fractures, bone and nail have to be covered with vital muscles.
- Delayed fracture healing with manifest or impending implant failure in the area of the femur diaphysis.
- Impending or evident pathological femoral shaft fracture in the case of multiple metastases and short life expectation

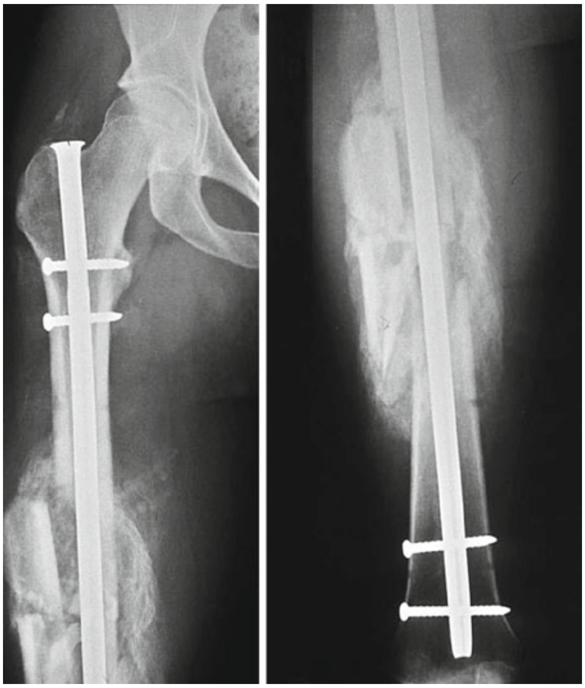

Fig. 21.2 Multifragmented femoral shaft fracture with locking nail and good callus sleeve

Necessary Instruments, Tools, and Implants

- Traction table or Müller distractor
- One or two image intensifiers
- Instruments for the insertion and removal of the nail
- A complete set of nails (diameter: 10–18 mm, length: 36–46 cm, in 2 cm intervals)
- Set of interlocking screws/bolts
- Proximal targeting device
- Distal targeting sleeve for interlocking, or alternatively a radiolucent drill attachment for the free-hand technique

Technique: The patient is placed on the traction table (Fig. 21.3), preferably in a supine position. The healthy leg can be positioned lower or on a gynecological support, in a way that it does not impair the X-ray examination and the assessment of the affected thigh. A synchronized X-ray view of the fracture in two planes is of great advantage. Anatomical reduction of the fracture is performed. The skin incision is made at the palpable tip of the trochanter major. The fascia and the gluteal muscles are split in the direction of the fibers for a length of 5 cm. The medullary cavity is then opened with a pointed curved awl at the medial border of the trochanter in the direction of the basis of the femoral neck, as medial as possible but not through the fossa piriformis. The guide wire for the reamer is inserted into the medullary cavity of the main fragments of the fractured femur. After reaming the medullary canal with the help of the guide wire (if the fracture is more fragmented, the reamer must cross the fracture zone by pushing it forward or retracting it without revolution), a nail of 1–2 mm smaller diameter than the last reamer head, already equipped with the proximal targeting device, is inserted through the guide wire in its definitive position. The length of the nail is judged by the length of the healthy femur, in case the length of the injured extremity cannot be determined exactly. If both femurs are broken, nails of the same length are implanted on both sides. Proximal interlocking is performed with the help of the targeting device as follows: incision of the skin and fascia, blunt separation of the muscle fibers onto the femur, insertion of the target sleeve onto the bone using the targeting device, drilling, and insertion of a screw of the chosen length in a way that the medial and lateral corticalis are grasped. The targeting device can then be removed. The distal interlocking requires the exact circular presentation of the interlocking holes at the distal end of

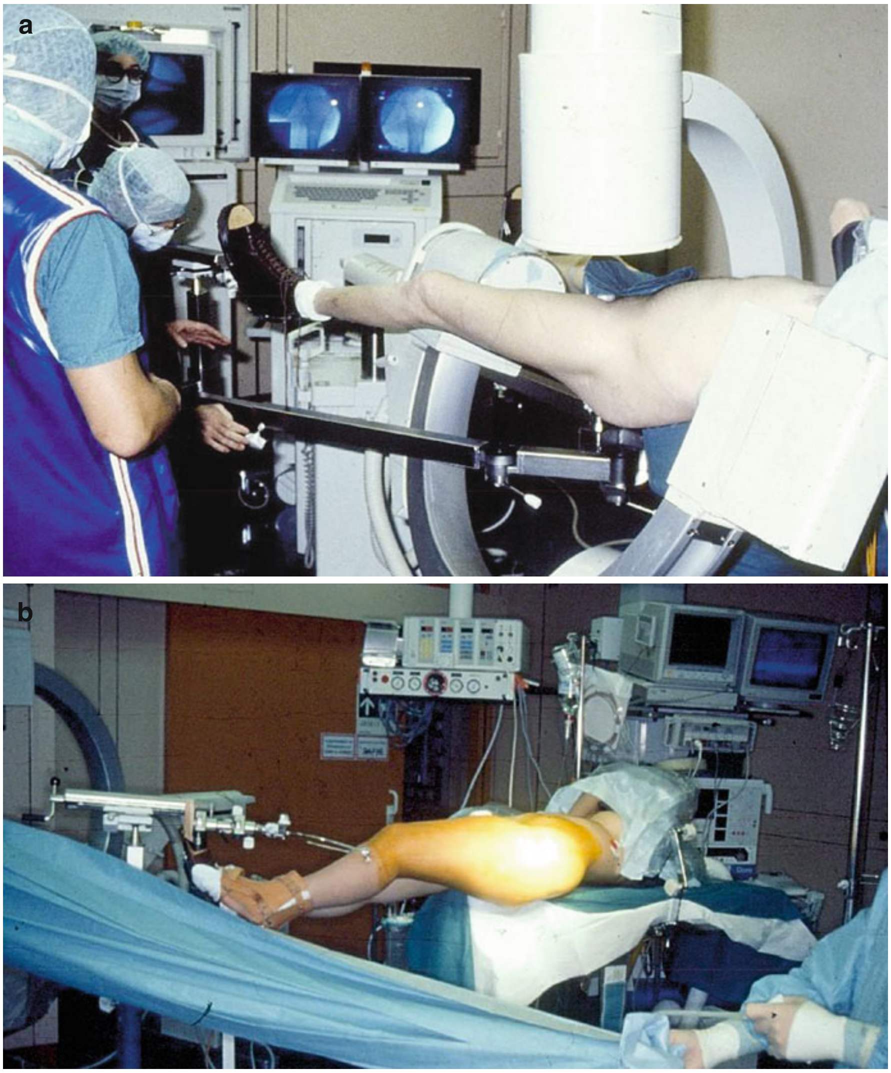

Fig. 21.3 Positioning on the fracture table. (**a**) Use of two image intensifiers for nailing of proximal femoral fractures. (**b**) Supine position for IM nailing

the nail using a precise lateral projection perpendicular to the holes with the help of the image intensifier. In this setting, the shadow of the scalpel is used to determine the height of the holes. As soon as the correct position is located, the skin and fascia are opened with a stab incision. The musculature is separated using a raspatory until contact is made with the bone. Under X-ray control, a targeting sleeve is brought in contact with the bone until the nail holes become visible through the sleeve on the X-ray image. The three holes (sleeve, lateral hole in the nail, and medial hole in the nail) have to be superposed and have to be seen as only one. With this maneuver, the correct location and the direction of the necessary drilling can be decided. After drilling through the target sleeve is completed, the length of the screw can be determined followed by the insertion of the first distal interlocking screw.

The second drilling is carried out in the same way. The usage of the radiolucent attachment to the drill is similar; the radiolucent equipment replaces the targeting sleeve. It is important that the interlocking holes appear as a *circle* on the screen. Drilling without an exact presentation of the holes is unsuitable and can lead to mis-drillings. If this happens, correction is troublesome and time- consuming. Therefore, failed drilling should be avoided by being cautious from the beginning. The insertion of the threaded bolts should happen exclusively with the help of a screwdriver and not with the help of a mallet.

Postoperative treatment: Twenty-four hours postoperatively, the dressing is changed and the drains are removed. Mobilization starts with weight bearing of the affected leg as tolerated due to pain. The more the restored bone is incorporated into transferring the load together with the nail, the earlier and more quickly load bearing of the injured leg can be increased. As soon as the first signs of callous bridging of the fragments are visible by X-ray, full-weight bearing can be started. Postoperatively and then after 1, 4, 8, and 12 weeks, X-ray controls are recommended. In case of a normal healing process, further follow-ups are suggested after 6 and 12 months postoperatively. The statically interlocked nail is removed after 18–24 months postoperatively if the healing process has been documented by X-rays. Otherwise, dynamization, cancellous bone grafting, exchange of the nail, and so forth, must be considered [4].

Advantages:

- Extension of the indications to all fracture types and locations situated between the second and fourth fifth of the femur, as long as the main fragments can be secured proximally and distally with the help of the interlocking bolts
- Minimally invasive method
- Easy removal of the implant

Disadvantages: Necessity of the use of all appropriate devices, such as the traction table and other reduction aids (as mentioned above), as well as of the image intensifier with its radiation exposure for the surgical team.

Complications:

- Surgical technical failures: poor or incorrect measures for reduction resulting in axis and rotational deviations, respectively, in leg length difference
- Invalid supplementary measures such as incorrect dynamization, resulting in shortening, secondary axis deviation, and delayed fracture healing due to insufficient follow-up controls
- Complaints at the point of insertion in the trochanteric region
- Breakage of the bolts: 2 % (Fig. 21.4)
- Breakage of the nail: 1 % (Fig. 21.5)

Healing Rate: 98 %

The Long Gamma-Nail and Alternative Implants (*Gliding Nail*, *Proximal Femoral Nail* (*PFN*), *Fi-Nail*, *etc*.) (Fig. 21.6)

Principle: This refers to the supplementation and combination of the intramedullary implant, which should control the longitudinal axis proportions of the femur with an implant that secures the Caput-Collum-Diaphysis angle. The union is established by enlarging the diameter of the proximal end of the nail in such a way that it can incorporate one or two screws or, for example, an H-, or double-T-profile-shaped second implant part, without evoking the danger of regular breaks in the nail at the connection point. The head-neck screw should be connected with the nail in a way that calculable sliding is possible in order to allow shortening of the proximal head-neck fragment. The diaphyseal part of the femur is neutralized and held in the desired axis through the bolting mechanism of the head-neck-screw (or equivalents) proximally and the two interlocking bolts distally.

Indication:

- Subtrochanteric fractures
- Trochanteric fractures with long fracture zone
- Trochanteric fractures combined with shaft fractures (fracture à deux étages)
- Femoral neck fractures combined with shaft fractures
- Subtrochanteric nonunions or delayed fracture healing with a threatening or already occurred implant failure

Necessary Instruments, Tools, and Implants:

- Traction table
- Two image intensifiers
- Special covers
- Instruments to open and enlarge the medullary cavity
- A proximal targeting device that is connected to the nail in order to insert the head-neck screw, screws, or nail implants in the proximal section of the femur
- A special set of nails with proximal nail notches at an angle of 120–140°, with differences of 5° and nail lengths of 30–40 cm with differences of 2 cm. Because of the antecurvature of the femur, a left- and right-sided nail is necessary in the set. The head screws are available in the lengths of 8–14 cm with differences of 5 mm.

Techniques:

- Closed reduction of the fracture, respective of the fractures, is performed; control images in two planes are taken with the image intensifiers.
- Limited open fracture reduction and protection using cerclages, titanium wires, or reduction clamps are only appropriate in exceptional cases: if the fracture is irreducible due to interposition of musculature or hip joint movement restriction [1].

Fig. 21.4 Nonunion distal femoral shaft with unstable nail and broken locking bolts. Salvage procedure with condylar plate

- For the appropriate choice of the implant the CCD angle has to be determined.
- The medullary cavity is opened with an awl at the tip of the trochanter major.
- The guide wire is inserted from proximal into the distal medullary cavity.
- The medullary cavity is reamed 2 mm larger than the diameter of the specific nail.
- The nail connected to the proximal targeting device is inserted with the help of the guide wire by hand into the medullary cavity. The distal end of the nail should reach the distal femur metaphysis and should point into the direction of the intercondylar region. If the adequate length has been chosen, the nail should be even with the proximal tip of the trochanter with a minimum distance of 1 cm to the intercondylar notch.
- The guide wire can be removed.
- After incision of skin, fascia, and musculature, the guide wire for the head screw is placed into the head-neck fragment with the help of the targeting device (in a way that the wire is positioned just caudal of the middle of the neck in the a.p. view and a little bit dorsal of the middle in the axial view). Now the length of the head-neck implant can be determined.
- The bed for the head-neck implant is prepared.
- The implant is inserted through the targeting device and the nail into the femoral head.
- After insertion of a drain, the proximal surgical wound is closed in layers.
- One image intensifier can be removed; the second one is used perpendicular to the nail axis in order to locate the distal nail holes. Stab incisions of skin, fascia, and musculature are made and the interlocking screws are placed into the nail holes after adequate drilling and freehand length measurement. (Distal targeting devices are now available on the market.)

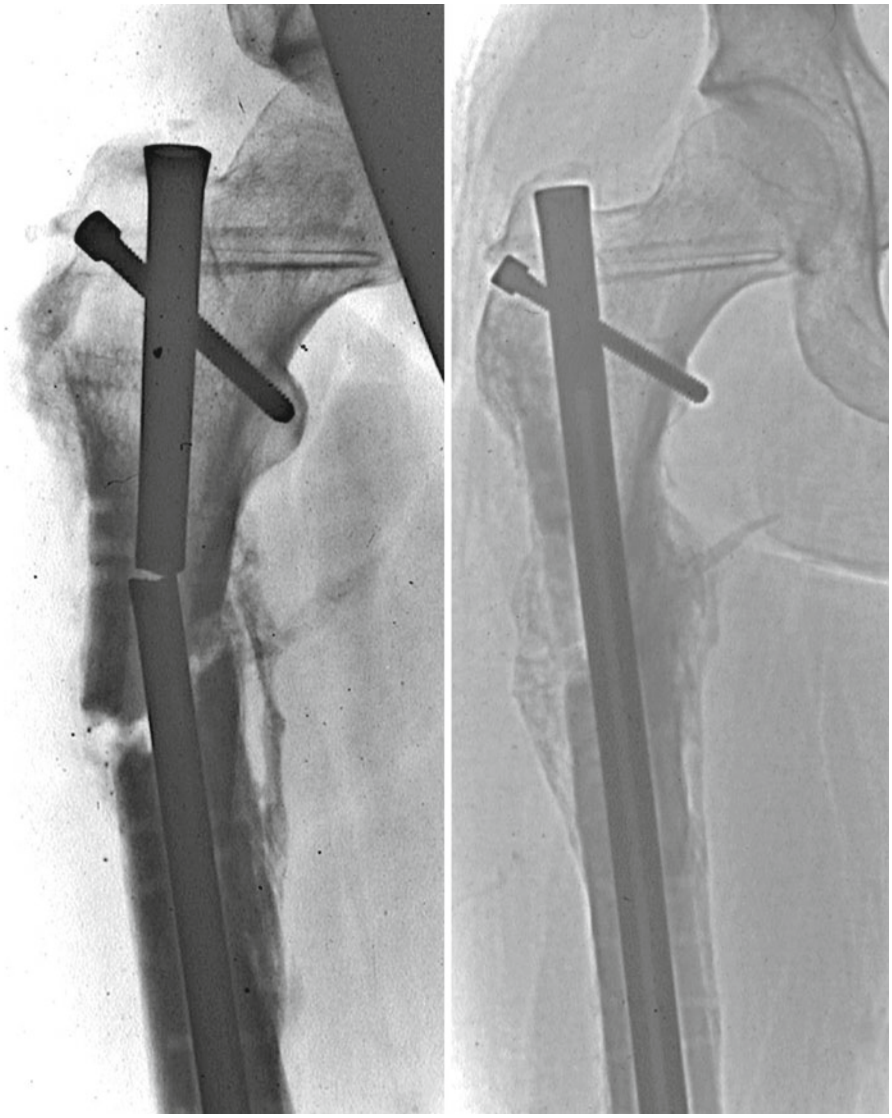

Fig. 21.5 Subtrochanteric nonunion: First fixation with a condylar plate, which failed; second operation with a locking nail, which is broken; necrosis of lateral cortex; salvage procedure: necrectomy, re-osteosynthesis with locking nail, cancellous bone graft

- The wound is closed distally; a final X-ray is taken.

Postoperative treatment: On the second postoperative day, the dressing is changed for the first time and the drains are removed. With mobilization, weight-bearing as tolerated (according to pain) is allowed initially, followed by a steady load increase up to full-weight bearing after a short time period. Starting 5 days after mobilization and then after 14 days, 6 weeks, and 12 weeks postoperatively, X-ray controls in two planes are necessary to assess the entire implant. Twelve days postoperatively, the stitches can be removed. It must be decided case-by-case whether the implant should be removed at all. Anyhow, this should not be done earlier than 18 months postoperatively.

Advantages:

- Covered, minimally invasive implantation technique
- Preservation of periosteal blood supply of the fracture fragments
- Higher average rate of bone healing

Disadvantages:

- Difficulty of achieving an accurate reduction, especially for surgeons who are not trained in the technique of closed reduction
- Higher radiation exposure

Complications: Due to surgical (technical) failures, axis deviations are possible. Infections (3 %) and fracture healing disorders (3 %) occur more often in combination with an open reduction [7].

Healing Rate: 96 %

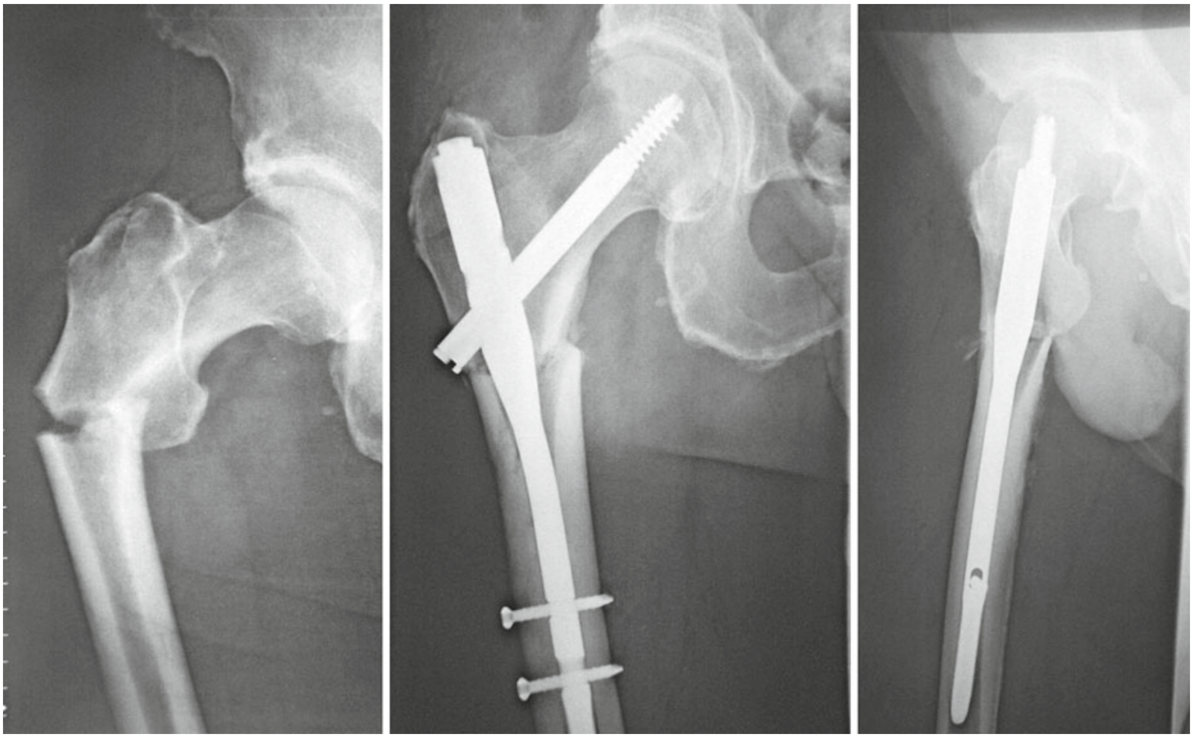

Fig. 21.6 Subtrochanteric fracture with PFN

21.5.2.5 Retrograde Femoral Nailing

Principle: Of all technical variations (like reamed or unreamed), orthograde and retrograde nailing of the femur mainly differ only in the point of insertion. At present, the accuracy of the targeting device for the use of this technique is ensured. Distal double interlocking is performed in the frontal plane from laterally. Then, the interlocking is carried out far away from the insertion point (but, in this particular case, close to the body center) in the same plane, or – depending on the implant – in the frontal and sagittal plane. If one of the shorter nails is used (up to 24 cm length), interlocking of the distal as well as of the proximal nail holes is reliably ensured by the targeting device.

Indications:

- Femur fractures with concomitant obesity, polytrauma, or multiple injuries
- Previously implanted hip endoprosthesis without loosening of the stem, meaning that the fracture is located at an adequate distance to the distal tip of the prosthesis
- Supracondylar femur fractures
- Femur and tibia fractures on the same side (Fig. 21.7)

Necessary Instruments, Tools, and Implants:

- Image intensifier
- Supracondylar Kirschner wire traction or Müller distractor as possible reduction aid
- Set to open and widen the medullary cavity
- Special targeting device for retrograde nails
- Nail set of 18–40 cm in 2 cm increments

Technique:

- A skin incision of 4 cm is made at the middle of the palpable ligamentum patellae proprium starting from the tip of the patella. The lig. patellae is split and Hoffa's fat pad is retracted.
- The insertion point is marked and its X-ray control is performed on the lateral view of the image intensifier. The insertion point is situated just above the fossa intercondyloidea in the caudal area of the trochlear groove and projects over the border between the front third and the second third of the roof of the incisura intercondyloidea as seen in the lateral X-ray image (Blumensat line). After the entry point has been identified the medullary cavity is opened.
- The guide wire is inserted into the medullary cavity of the distal and proximal main fragment of the femur.

Fig. 21.7 Homolateral femoral shaft and lower leg fractures: retrograde nailing of the femoral fractures and antegrade nailing of the tibia via one incision

- The medullary cavity is reamed or the decision is made to use a nail of smaller diameter.
- The appropriate length has to be chosen. It is recommended to use a longer nail in order to strictly avoid ending up with the nail in the middle of the diaphysis (which is a dangerous site for further fractures due to weakening of the bone in the area of the interlocking holes).
- The guide wire can be removed.
- Interlocking distally and proximally with the help of the targeting device or using the "freehand" technique proximally in the predetermined holes/planes of the chosen nail
- Irrigation of the knee joint with special care to remove drilling products
- Placement of a drain into the knee joint
- Suture of the ligament
- Suture of the skin

Postoperative treatment: DVT prophylaxis is mandatory. The dressing is changed on the second postoperative day. According to the amount of secretion, the drain should be removed 2 or 3 days after the surgery. When the postoperative pain has subsided, the knee joint should be mobilized as tolerated due to pain using continuous passive motion with increasing range. On the 12th postoperative day, the stitches are removed. Non-weight bearing is prescribed until callous bridging of the fracture area is seen on the X-rays. X-ray controls should be performed on the 5th and 14th postoperative day and then after 4, 8, and 12 weeks. Finally, the implant can be removed between the 12th and 18th month after surgery.

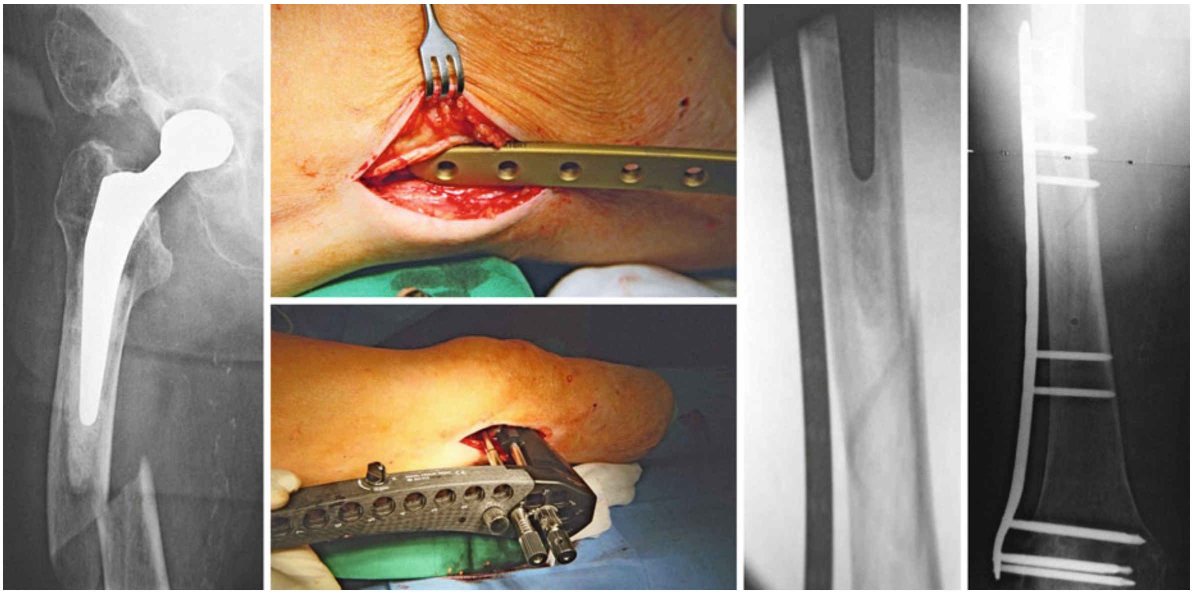

Fig. 21.8 Periprosthetic fracture: Percutaneous fixation with LISS

Advantages:

- Special positioning techniques are not applied.
- The technical restriction to perform orthograde intramedullary osteosynthesis in patients who are extremely obese can be overcome, as long as the targeting device can be used.

Disadvantages:

- Necessity to open the knee joint
- Drainage of the medullary cavity into the knee joint can provoke a hemarthros. In case of an infection, the knee joint will be involved in this process.

Complications:

- Primary and secondary axis deviation, leg-length discrepancies
- Hemarthros
- Increased risk of fracture at the point of proximal interlocking or at the proximal nail tip
- Migration of the nail in a distal direction (cutting through mechanism)
- Loosening of the bolt, breakage of the bolt: 6 %
- Breakage of the nail: 4 %
- Increase in knee joint complaints

Healing Rate: 92 %

21.5.2.6 Plate Osteosynthesis

Principle: The fracture fragments are fixed to a metal plate, which is placed juxtacortical, by screws, usually positioned on the lateral side, in a way that each of the two main fragments is held by at least three screws. Generally, to attain the needed stability two technical procedures can be used for restoring axis and length proportions:

- The fragments are reduced anatomically; interfragmentary compression and restoration of the load capacity of the bone are achieved by supporting the fracture with an osteosynthesis plate.
- Axis and length of the main bone fragments are aligned; the plate is fixed with angular stable screws. Eventually, some larger intermediate fragments can be stabilized by using conventional lag screws or angular stable screws either through the plate holes or next to the plate, depending on their position .

Indication: Using plate osteosynthesis in order to stabilize a femur shaft fracture has to be considered as second choice. However, this method should be considered if a simultaneous reconstructive procedure with large exposure is necessary. Nevertheless, plate osteosynthesis is the method of choice for periprothetic fractures, especially after total hip replacement (Fig. 21.8), where the femur shaft component is not loosened.

Finally, plate osteosynthesis may be a good choice for salvage procedures in delayed unions and nonunions of the femoral shaft (Fig. 21.9).

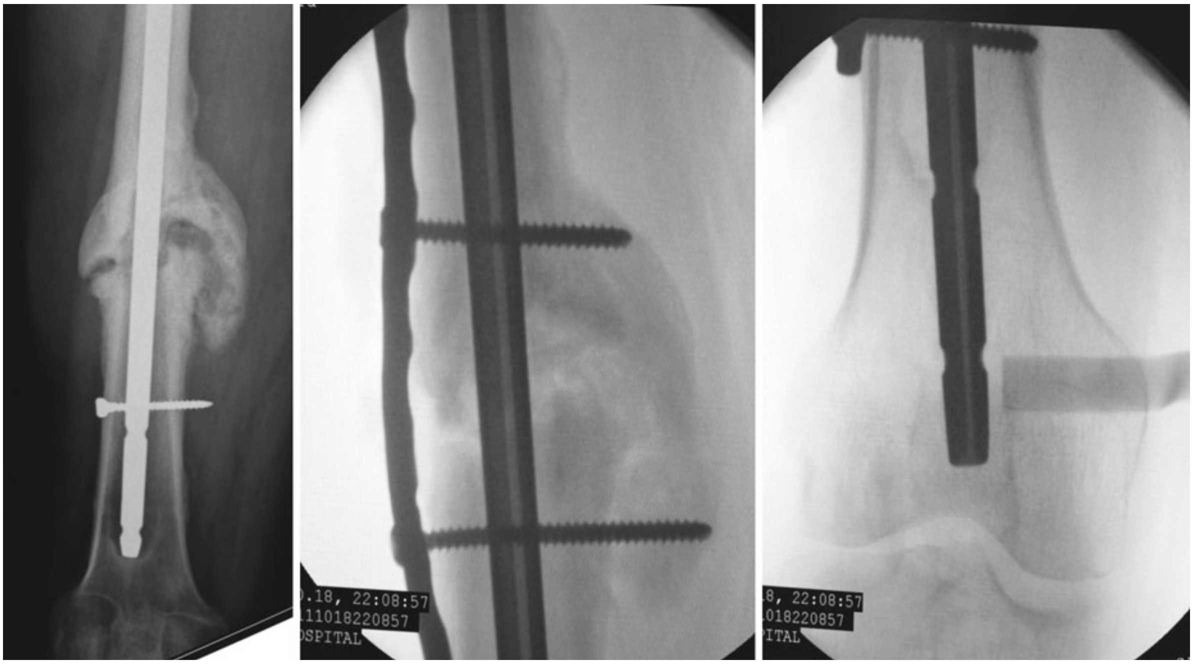

Fig. 21.9 Nonunion with unstable nail and misplaced locking bolt, re-osteosynthesis with a reamed nail, decortication, and antirotation plate

Necessary Instruments, Tools, and Implants:

- Soft tissue instruments
- Instruments for reduction
- An image intensifier to control the results of the reduction
- A set of plates
- A set of screws
- Plate adjustment instruments
- A distractor or a traction table as a reduction aid

Technique: There are two types. Using the lateral approach to the femoral shaft with the patient either in a lateral decubitus or in a supine position, the exposure of the fracture is performed in such a way that connections between the musculature and the periosteum of existing intermediate fragments are maintained as much as possible. The bone is reconstructed from the distal to the proximal end, or vice versa, using lag screws and reduction clamps and, if necessary, temporary cerclages. A plate with suitable width should be chosen, aligned, and adjusted. It must be long enough that the two main fragments can be caught proximally and distally each with three screws equal to six cortices.

Fractures that are located in the periphery of the shaft (either near the hip joint or knee joint) may be difficult to stabilize with a simple, universal plate construction. Due to the short lever arm of the connection in the short fragment versus the long lever arm in the long shaft fragment, there is a potential risk that a mechanical deficit with loosening or tearing out of the screws from the shorter fragment will lead to a mechanical failure of the implant (Fig. 21.10). The differences in the mechanical properties of the metaphyseal and the diaphyseal bone also play a decisive role. In order to compensate for these mechanical deficits, special plate systems have been developed (Fig. 21.11), which are partly aligned to the anatomy and usually need a special application system for implantation. Prior to implantation, the surgeon must read in detail with the instructions, because, despite similar characteristics, they can vary for the chosen implant or company. Therefore, the technical standards can demand too much of even the most talented improvising surgeon. As a consequence, the wrong implantation technique can be the cause for unpardonable mistakes and failures.

MIPO or MIPPO technique: In the *m*inimally *i*nvasive *p*ercutaneous *o*steosynthesis (MIPO) or *m*inimally *i*nvasive *p*ercutaneous *p*late-*o*steosynthesis (MIPPO) technique, indirect reduction of the fracture is performed with the help of a distractor and the assistant pulling. A 5–7 cm incision to the femoral shaft is made, proximally and distally in front of the septum intermusculare. The musculature of the lateral vastus

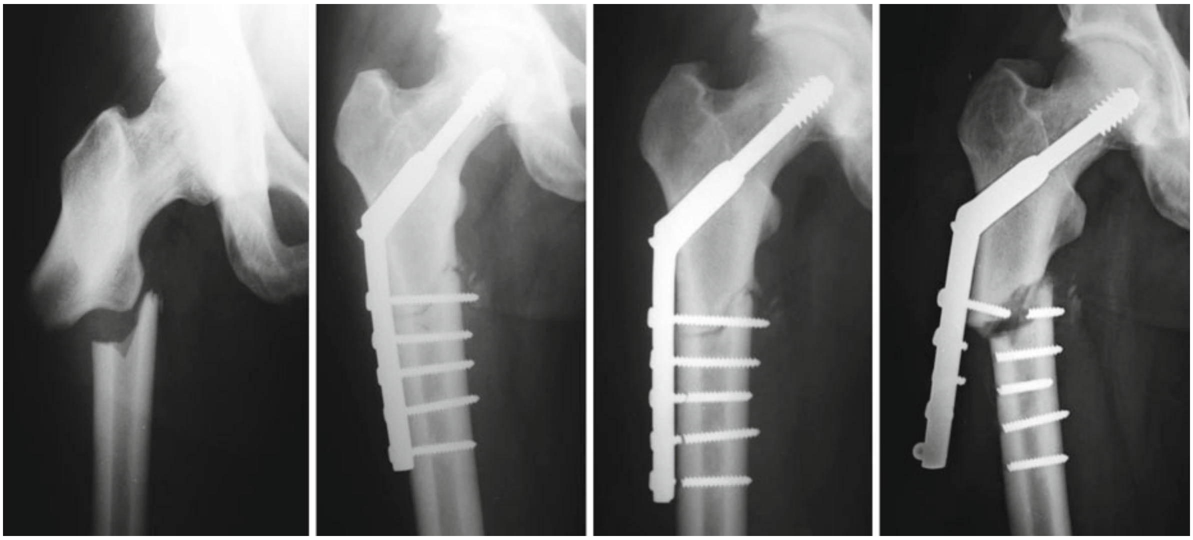

Fig. 21.10 Subtrochanteric nonunion and failed fixation using an inappropriate concept

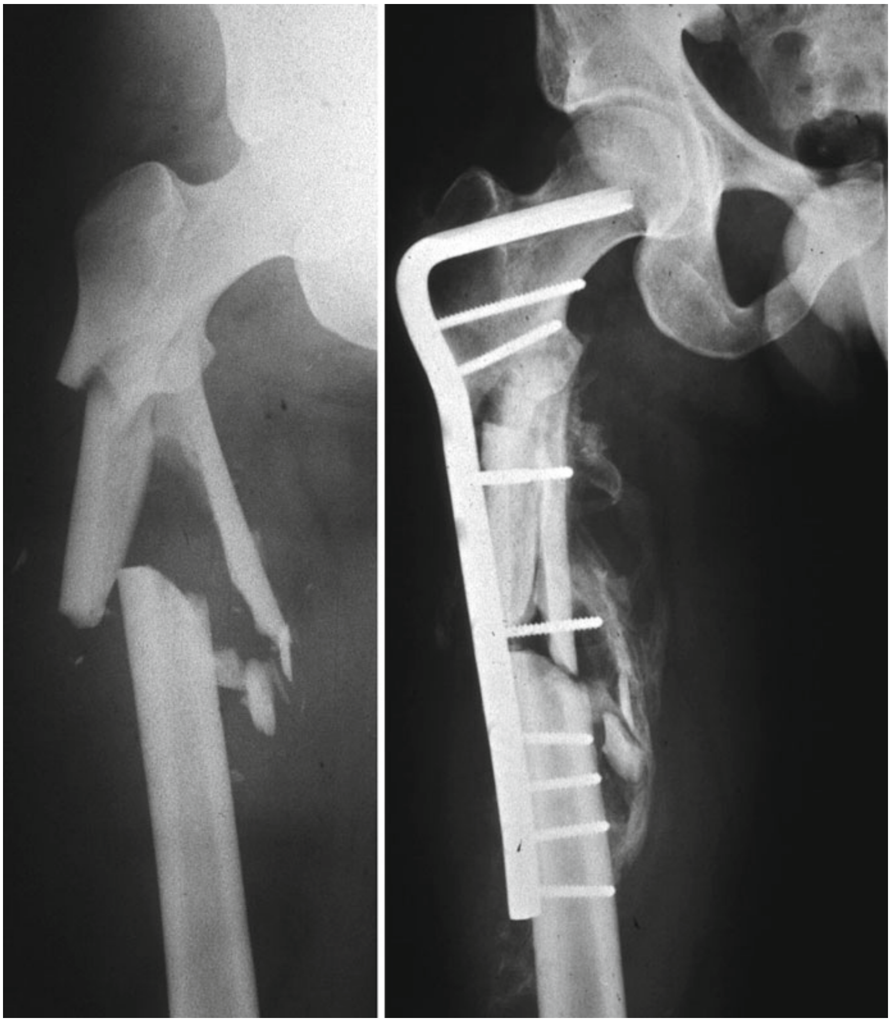

Fig. 21.11 Neglected comminuted subtrochanteric fracture in a polytrauma patient transferred with severe thoracic trauma, bridging fixation with condylar plate

is tunneled in order to get enough space at the bone for the plate (with the designated length and precontouring). The implant is inserted from distally with rigorous contact to the bone. Sometimes this step is performed the other way around (insertion from proximally), depending on the thickness of the soft tissue and the localization of the fracture. The armament of the plate holes proximally and distally is carried out through the incisions over the main fragments and of the intermediary holes using the percutaneous technique (stab incision of the skin and fascia, retraction of the musculature with a raspatory, localization of the plate hole, insertion of the drill protection sleeve, alignment of the drill direction after deciding which technique to use – regular screw or lag screw, insertion of the screw).

The angular stable plate systems are especially suitable for percutaneous osteosynthesis techniques, because the shoulder of the screw interlocks with the plate hole via a threaded connection (e.g., *LCP* = *l*ocking *c*ompression *p*late, *LISS* = *l*ess *i*nvasive *s*tabilization *s*ystem). Special requirements include choice of the plate, plate alignment, and armament of the plate holes with the respective screws using the targeting sleeve system. The length and type of the screws (mono- or bicortical, conventional lag and compression screws), which follow the principles of absolute or relative stability, are used according to the given requirements and to the preoperative planning. The intraoperative application of an image intensifier, especially with the percutaneous technique (to estimate length, axis, and plate alignment) provides indispensible benefit.

Pronounced bone defects within a comminution area and cases of delayed fracture healing demand local measures to boost the quality of fracture healing. The analysis of the local vascularity and of the given stability indicate the right direction for detecting measures that are reasonable to eliminate this particular fracture healing disorder. Assuming adequate stability, the well-timed transfer of the cancellous bone is indicated.

Advantages: As this technique can be used for all purposes, standard instruments are available that normally comply with the necessary expectations.

Disadvantages:

- Specific reduction aids, such as distractor, external fixator, or traction table are frequently required.
- The need for an intraoperative X-ray control should be recognized in time, otherwise, an appropriate open surgical technique should be used to enable the assessment of correct implant positioning.
- The blood supply of the fracture fragments is endangered by exact anatomical assembly and fitting of all the fragments.
- Reduced blood supply caused by a plate that is pressed onto the bone surface (reduction of the periosteal circulation) and the denuding of the fracture fragments can lead to delayed fracture healing and to an increased risk of infection.
- From a morphological point of view, the bone section next to the plate is changed adversely. On the one hand, resulting from decelerated bone metabolism caused by reduced blood supply and, on the other hand, due to the mechanical protection of load transmission onto the bone caused by the plate ("stress protection"). Therefore, after removing the plate, an adequate regeneration process (remodeling) has to start. In this time period the already-healed bone is at risk for re-fracture.
- The implantation techniques of the anatomical and specific plate systems do not automatically correspond to the standards of conventional plate implantation techniques. As a consequence, preoperative planning and accurate memorization of the surgical steps are crucial.

Complications:

- Infection: 3 %
- Delayed fracture healing: 15 %
- Pseudarthrosis: 5 % (Fig. 21.12)
- Re-fracture: 6 %

Healing Rate: 94 %

21.5.2.7 External Fixation

Principle: The fracture is stabilized through an assembly of percutaneous pins, half screws, or K-wires that are mounted together on frames and rods beyond the integument (skin level). The main fragments of the femur should be caught in two planes and in two different heights, as close to the fracture as possible and as far away from the fracture as possible; the pins or ring constructions have to be connected through rods as close to the skin surface as possible. Furthermore, the bone length and

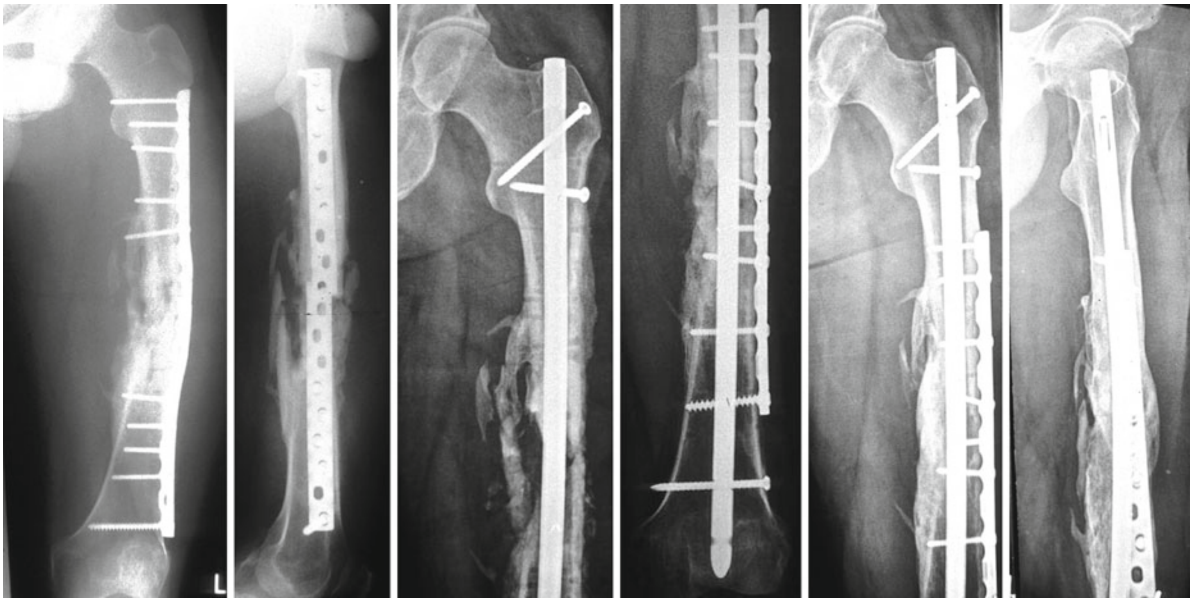

Fig. 21.12 Broken plate after severe open femoral fracture, re-osteosynthesis with locking nail, rotational instability with migration and removal of the second distal locking bolt, bony healing after augmentation with an antirotation plate

axis have to correspond to the predefined anatomical conditions.

Indication:

- Open fractures with a higher grade of severity, especially when the vitality of the soft tissues is vulnerable or doubtful and coverage of the bone with nourished soft tissue cannot be guaranteed
- Infected fractures
- Axis and length correction in the area of the femoral shaft, callus distraction (Ilizarov)
- Temporary fracture fixation or a definite fracture stabilization within polytrauma care, orthopedic damage control
- Pediatric femur fractures, especially if they tend to shorten (Figs. 21.13 and 21.14)

Necessary, Instruments, Tools, and Implants:

- System dependant:
  - Schanz screws, Steinmann pins, rods or tubes of different lengths, inserts for a connection between pin and rod or rod and rod
  - K-wires, rings and ring parts of different diameters, rods or rod inserts, which enable connections between the ring constructions
  - Hybrid constructions that enable a connection between the systems mentioned above
- Image intensifier (C-arm)
- Traction table, if necessary

Technique:

- Acute care
- Planned correction

Advantages: There are no adverse effects on the blood supply of the bone. The risk of infection is reduced because no "avital" implants are inserted that can be colonized by germs and therefore lead to acute or chronic osteitis and/or osteomyelitis. A particular advantage is the speed with which the external fixator can be applied in case of critical and unusual circumstances. Furthermore, it is an adequate alternative to elastic intramedullary nailing for treating femur fractures in children. Secondary corrections, referring to the desired axis or pin position, are possible without great effort.

Disadvantages and Complications:

- Deficiency in stability due to construction or, in contrast, an excessively pronounced rigidity or stiffness of the respective system
- Infected pins (especially in areas of the femur with plenty of soft tissue) caused by rubbing of the soft tissue against the pins or wires as the result of skin, fascia, and musculature shifting during mobilization

Fig. 21.13 Femoral shaft fracture in a young boy with external fixator

- Pin loosening caused by infection or for mechanical reasons
- An increased frequency in delayed fracture healing, which is partly explained by the irritated local vascularity due to the injury itself and partly by the lack of stability and by increased or suppressed play between the fracture fragments
- A higher rate of pseudarthrosis
- Insufficient wearing comfort
- Temporary and often definite immobility of the hip joint, but mainly of the knee joint, caused by persistent adhesions of the soft tissues to periosteum and bone due to pin-related transfixation
- Frequent necessity for corrections and additional interventions

  Healing Rate: 90 %

21.6 Differential Diagnosis

Femur fractures are generally caused by high-impact trauma. If there is inconsistency between the fracture incident and the provoking impact, the probability of a pathological fracture is very high. It is based on a dysfunction of mechanical attributes of the bone resulting from metabolic disorders, undesired medication-related side effects, infections, cancer, and others. The main question of fracture diagnostics, especially of the femur, focuses on sorting out whether it is a regular, explainable fracture or a pathological one. To clarify any open questions in this regard, accurate X-ray images in two planes (eventually completed with oblique images), CT scans, and especially MRI examinations are helpful. However, scintigraphy only plays a minor role for differential diagnosis today.

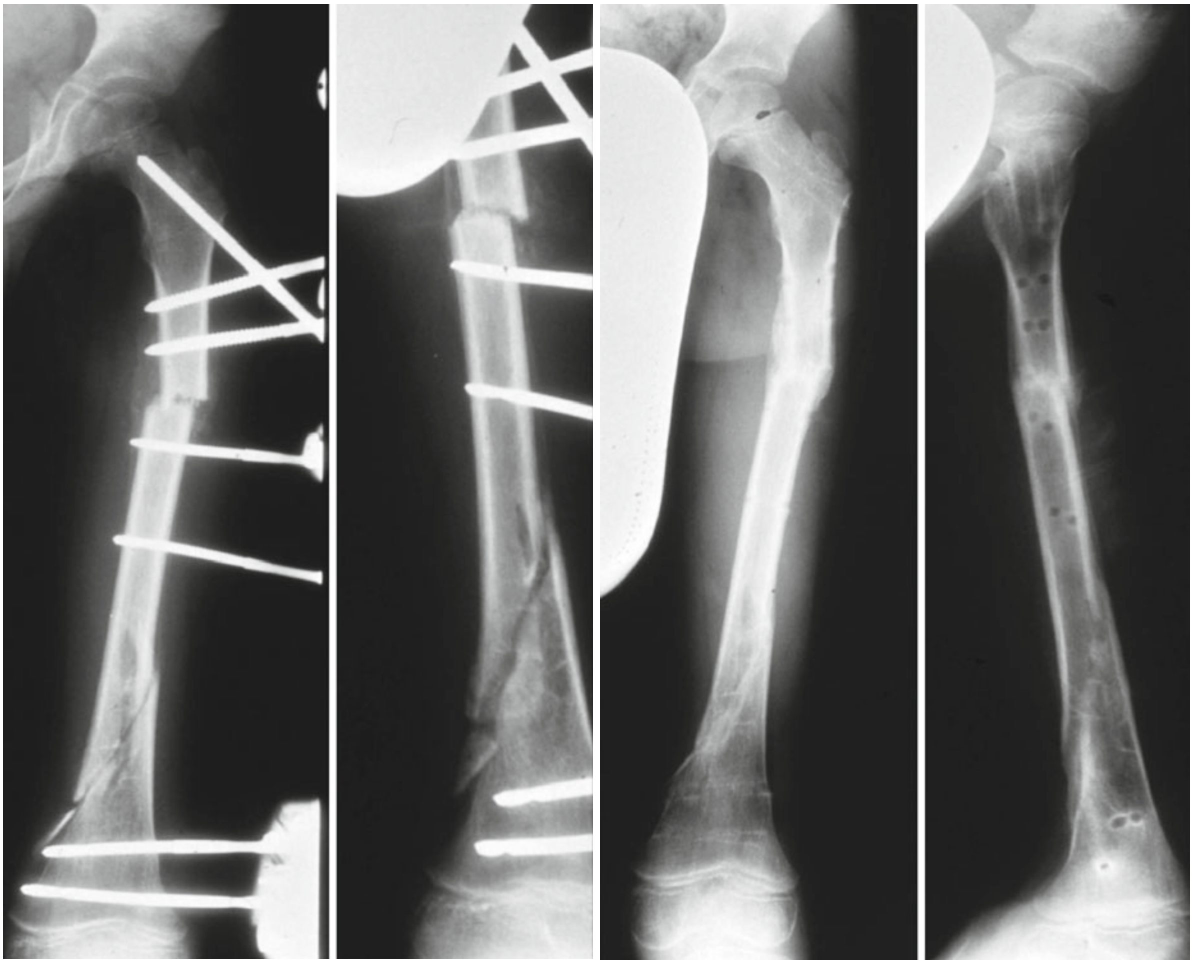

Fig. 21.14 Femoral shaft fracture in an adolescent healed with external fixation

21.7 Prognosis and Surgical Principles

With regard to bone healing, the prognosis of a femoral shaft fracture is good. With regard to lifesaving, it depends on the extent of blood loss (shock, organ failure), injury pattern in case of multiple injuries, the systematic distribution of medullary cavity contents (fat embolism syndrome), and their impact on particular organs and organ systems. Considering the relevant treatment guidelines – indication for surgery, criteria for operability, time of surgery, choice of method and implant, analysis of the characteristics of each fracture, and the investigation of the interaction with concomitant injuries – are the secret to success and therefore crucial for prognosis optimization. Secondary factors are follow-up treatment, X-ray controls, and rehabilitation regimen, which should all be offered by an institution for the benefit of the injured person.

- Correct diagnosis
- Correct ascertainment of concomitant injuries and side-effects
- Correct grading of operability and time of surgery
- Correct choice of method and implant
- Correct initial and definitive treatment for isolated femur fractures
- In the case of multiple and polytraumatized patients, correct application of the orthopedic damage control principles, including correct planning and an eventually necessary change of the treatment modality [5]

Table 21.1 Indication for the use of individual osteosynthesis methods or implants

Type of osteosynthesis	Subtrochanteric fracture							
	Closed fracture*				Open fracture*			
	GI	GII	GIII	GIV	OI	OII	OIII	OIV
External fixator	–/+	–/+	–/+	–/+	–/+	–/+	++	+++
Interlocking nail reamed	–/+	–/+	–/+	–/+	–/+	–/+	–/+*	–/+*
Interlocking nail unreamed	–	–	–	–	–	–	–	–
Long Gamma-Nail (*Alternative implants*)	+++	+++	+++	+++	+++	+++	+++*	++*
DHS with long plate	++	++	++	++*	++	++	++*	+*
DCS proximal	++	++	++	++*	++	++	+*	+*
Condylar plate proximal	+	+	+	+	+	+	+*	+* ++
LCP trochanteric	+	+	+	+*	+	+	+*	+*

– not indicated, –/+ single indication, special case, + indicated, ++ good indication, +++ excellent indication, preferred
*Bone and implant covered by vital soft tissue as a precondition

Table 21.2 Indication for the use of individual osteosynthesis methods or implants

Type of osteosynthesis	Diaphyseal femoral fracture							
	Closed fracture*				Open fracture*			
	GI	GII	GIII	GIV	OI	OII	OIII	OIV
External fixator	–	–	+	++	–	+	++	+++
Intramedullary nail (Küntscher)	+	+	+	+	+	–	–	–
Interlocking nail reamed	+++	+++	+++	++	+++	++	+*	–/+*
Interlocking nail unreamed	–/+	–/+	++	+++*	–/+	–/+	++*	+++*
Long Gamma nail (deux etage fx.)	+	+	+++	+++	+++	++*	++*	–/+*
DHS with long plate (deux etage fx.)	+	+	+	+*	+	+	+*	–/+*
DCS proximal (deux étages fx.)	+	+	+	+*	+	+	+*	–/+*
LCP, *DCLCP* (*periprosthetic fx.*)	++	++	++	+*	++	++	+*	–/+*
Percutaneously inserted plate (MIPO)	+	+	+	–/+*	+	+	+*	–/+*
DCP distal	–/+	–/+	–/+	–/+*	–/+	–/+	–/+*	–/+*
Condylar plate distal	–/+	–/+	–/+	–/+*	–/+	–/+	–/+*	–/+*
LISS	–/+	–/+	–/+	–/+*	–/+	–/+	–/+*	–/+*

– not indicated, –/+ single indication, special case, + indicated, ++ good indication, +++ excellent indication, preferred
*Bone and implant covered by vital soft tissue as a precondition

- Correct and consequent follow-up treatment, observing the undisturbed healing process, identifying healing disorders in time, and initiating every measure required to control them (Table 21.1 and 21.2)

21.8 Femur Fractures and Polytrauma

Seventy percent of all polytraumatized patients suffer from fractures of the extremities. The most common fracture of a long bone in this context is the femur fracture. A thorax trauma is present in more than 80 %, a craniocerebral trauma in 70 %, and an abdominal trauma in 65 %.

The primary prognosis of the patient depends on the vehemence of the combined effects of injuries to the vital body functions, in terms of immediate or indirect threat to life.

Hypoxemia, circularity collapse and instability, shock organs, or failing of single organ functions or of multiple organs at admission should be interpreted as extremely critical signs. However, the concomitant femur fracture also has an influence on the prognosis, but under the above-mentioned circumstances its importance is negligible. The femur should be placed in a pain-free or pain-reduced position.

The next steps are intubation, ventilation, establishment of a central venous access for volume compensation, and monitoring of the volume demand [(TEEC, pressure in the large (RR invasive – a. radialis)) and the small circulation (pulmonary catheter)], with the objective of stabilizing the circulation (RR syst. > 100 mmHg, pulse < 100/min without rhythm disorders, urine production > 50 ml/h).

Simultaneously with securing good gas exchange and stabilizing the circulation, systematic clinical and radiologic diagnostics are carried out to detect the complete injury pattern.

The therapeutic algorithm depends on evaluated vital parameters, such as gas exchange (also the peripheral tissue oxygenation) and circulation (blood pressure, pulse rate, hematocrit, blood clotting, urine production, body temperature, brain pressure).

The aim is to eliminate peripheral pain irritation caused by the movement of bone fragments. A patient who is "stable" (hemodynamically stable, no organ dysfunction, no need of catecholamines, diagnostics regularly finished) can be treated risk free with primary definitive osteosynthesis, or primary total care (PTC). However, if any doubt is present, further dangers for the patient (hypoxemia, hypothermia, fat embolism, ARDS, organ and multiple organ failure) should be avoided and the rules of damage control orthopedics (DCOS) should be followed, with an external fixator primarily (Fig. 21.15) and definitive osteosynthesis after stabilization of the patient [3, 5, 8, 18] (Table 21.3)

21.9 Pathological Femur Fractures

These raise a specific question. It is important to insist initially on an exact diagnosis, to take an anamnesis, and to include preliminary findings in case of a high probability of a pathological fracture. If visceral metastases are detectable, the diagnostics have to be extended so as to distinguish between solitary and multiple metastases. Furthermore, it must be determined what kind of primary tumor is present and whether oncological therapy has been initiated in the past. With the help of these indicators and the assessment of the patient's general health status, the prognosis quo ad vitam should be predicted (Table 21.4).

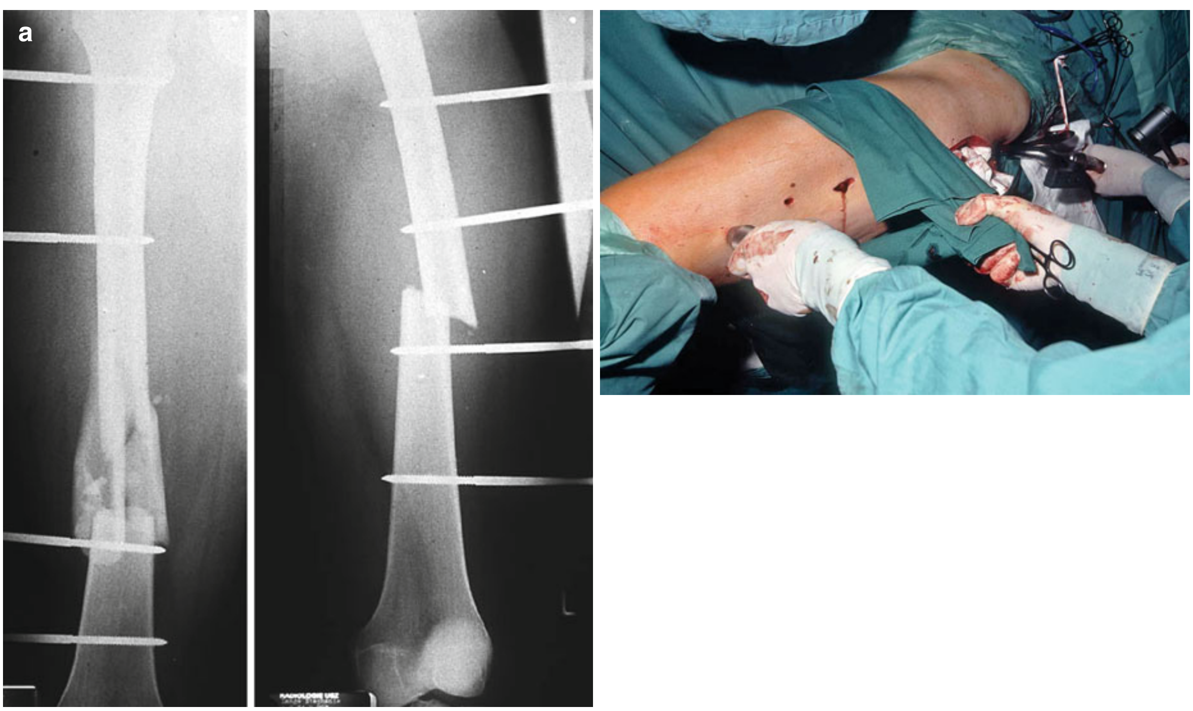

Fig. 21.15 Polytrauma with bilateral femoral shaft fractures and exsanguinating hemorrhage from abdominal injuries: (**a**) External fixators for both femora as damage control. After full resuscitation in the ICU, nailing of the femoral fractures on day 6 post trauma. (**b**) Uneventful bony healing of both femora

Fig. 21.15 (continued)

Table 21.3 Therapeutic algorithm for the care of a femoral shaft fracture in the context of a polytrauma

Gas exchange and circulation stable, all diagnostic investigations are completed	Gas exchange stable and circulation is easy to stabilize, diagnostic investigation feasible					Gas exchange secured by complex respiratory measures, circulation unstable, diagnostics delayed, acute surgery to stop blood loss is indicated		Gas exchange heavily disturbed, circulation cannot be stabilized, in extremis
No indication of acute surgery in the body cavities indicated	Acute surgical intervention to stop bleeding not indicated		Indication for acute cavity revision surgery, patient definitely needs to be stabilized		Indication for acute cavity surgery, assessment of circulation uncertain, stabilization doubtful, unsteady, organ failure impending	Stabilization of ventilation and circulation possible, definite restoration of the cavity injury could not be completed, damage control surgery (DCS)	Stabilization only possible with emergency measures e.g. tamponade	Improvement of ventilation and circulation not possible, manifest irreparable organ failure, diagnostic investigation terminated
Treatment of the femur shaft fracture primary as under elective conditions	Stable condition – treatment of the femur shaft fracture as under elective conditions	Condition not definitely assessable – DCOS – external fixator, possible sec. change of method	Stable condition can be achieved – treatment of the femur shaft fracture as under elective conditions	Condition cannot be judged for certain – DCOS – external fixator, possible sec. change of method	DCOS, external fixator, change of method is possible, subject to further developments, possible definite	Continuation of diagnostic investigation – DCOS, external fixator, subject to change of method	Postponement of diagnostic investigation necessary – DCOS – external fixator, further proceedings subject to further developments	Positioning, ICU

DCOS Damage Control Orthopedic Surgery, *DCS* Damage Control Surgery

Table 21.4 Algorithm for the care of pathological femoral shaft fractures

	Benign lesion	Solitary metastasis	Multiple metastases	Pathological fracture with a solitary metastasis	Pathological fracture with multiple metastases	Malign bone tumour
Resection	Yes	Yes	No, exceptionally	According to oncological criteria	No	After the diagnosis has been verified
Cement filling	Not routine	Possible	Possible	In the scope of a compound osteosynthesis	In the scope of a compound osteosynthesis	? Temporary, definite?
Plating	If in danger of fracture	If in danger of fracture	Exception	Preferred	In a specific indication	Restoration
Interlocking nailing	exception	0	If in danger of fracture	Exception	Routine	Exception e.g. in combination with grafts
External fixation	0	0	0	Exception	Exception	Exception
Tumor prosthesis	?	Depending on indication, localization, primary tumor	If radicalness is allowed, metastasis only in one femur –femur replacement (?), visceral and skeletal diagnosis of the prognosis is a precondition	In terms of oncology radicalness	Possible exception, if the metastases are in one femur and another form of stabilization does not seem possible	After the diagnosis has been secured and chemotherapy
Allograft	Possible	No	No	No	No	Possible
Amputation	No	Exception, osteosynthesis not possible, pain relief not possible in any other way	Exception, osteosynthesis not possible, pain relief not possible in any other way	Exception, osteosynthesis not possible on technical grounds, pain relief not possible in any other way	Exception, osteosynthesis not possible pain relief not possible in any other way	In tumors not sensitive to chemotherapy, in an existing pathological fracture, if it is not expected or possible to check the tumor
Treatment personnel	Tumor team, specialist	Known primary tumor: routine; otherwise search for the primum, if no success eventually tissue extraction from the metastasis for histological examination via fine needle biopsy	Routine, possibly tumor team provided that oncology treatment is not already exhausted	Routine, consultation with the tumor team or a specialist is an advantage	Routine	Specialist, tumor team

Treatment tactics	Securing diagnosis, elimination of the tumor, autologous or homologous construction of the skeleton section	Checking the diagnosis; systematic chemotherapy, local irradiation therapy, poss. radionuclide therapy, embolization, prevention of a pathological fracture, poss. prophylactic osteosynthesis	Checking the diagnosis, systematic chemotherapy, local irradiation therapy, poss. radionuclide therapy, embolization, prevention of a pathological fracture, poss. prophylactic osteosynthesis on the femur and/or on other sections of the skeleton	Is radical elimination of the tumor possible? Resection, local precautions, e.g. phenol treatment, construction of the defect	Stabilization of the pathological fracture, by passing the metastases section	Securing diagnosis with CT, MRI, fine needle biopsy, sequential chemotherapy, en-block tumor resection including the soft tissue biopsy canal, deformity replacement, determining tumor cell sensitivity, after treatment
Aim of treatment	Prevention of a relapse, correct leg length, leg axis and function of the extremities	Resection and reconstruction according to oncology criteria, as long as this seems opportune on grounds of the primary tumor and the reliability of the examination results	Tumor growth containment, eliminating pain or pain relief	Successful treatment, functional, satisfactory lower extremity	Good function of the lower extremity for life	Successful treatment, good functional results for the lower extremity
Prognosis	Good	Subject to primary tumor and preliminary treatment	Subject to primary tumor and preliminary treatment	Subject to primary tumor and preliminary treatment, quality of the local surgical measures and fracture treatment	Subject to primary tumor and preliminary treatment, quality of the local surgical measures and fracture treatment	Subject to the histological diagnosis, quality of treatment and team, tumor sensitivity to chemotherapy, general compliance of the patient, respectively

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Distal Femur Fractures

22

Arne Berner and Michael Schütz

22.1 Introduction

Distal femur fractures are severe injuries that can present some clinical challenges to orthopedic and trauma surgeons. They mainly affect young patients following high-energy traumas or elderly patients with osteoporotic bone after low-energy traumas. Distal femoral fractures represent a small proportion of all fractures, between 6 and 7 %, with an incidence of 12/100,000 population [1].

The treatment of distal femur fractures has changed over the last decades. The main goal of the past surgical treatment was high primary stability and anatomical reconstruction of the joint as well as the metaphyseal fragments. This was achieved by an extended approach of the operative field, often more excessive periosteal stripping, and the use of multiple lag screws to achieve high primary stability. Later on, it was recognized that extensive exposure could lead to diminished blood supply to the fracture zone with the consequence of delayed union or nonunion. In the mid-1990s, it became gradually more accepted that absolute stability of a multifragmentary metaphyseal/shaft fracture is not required and that an internal fixation construct with flexibility could lead to secondary bone healing with excellent outcome, as long as the anatomical alignment, rotation, and length were kept right. Using these biological-plating techniques to preserve fragment vascularity primary bone grafting is hardly required anymore [2, 3]. The "rediscovered" importance of gentle soft tissue handling and the vascularity of the fragments led to the development of several new implants applying minimally invasive techniques for distal femoral fractures [4–6]. These techniques avoid direct exposure of the metaphyseal fracture site, using a precontoured locking plate as an extramedullary internal splint or a retrograde intramedullary nail as an intramedullary splint. It was shown experimentally that this more "biological" approach lead to less iatrogenic blood disturbance [7], resulting in a less disturbed bone vitality and earlier fragment callus bridging [2, 8–11].

22.2 Etiology

Distal femur fractures in young male patients appear mostly in the context of multitrauma related to road traffic accidents (over 50 % of distal femur fractures in this age group) [12, 13]. The fracture occurs as a result of direct force to the flexed knee. Additional injuries of the trunk and the skull are frequent. According to the literature and our own observations, several patients have accompanying injuries, such as patellar fracture in 10–15 %, knee ligament instability in 20–30 %, and further bony lesion of the ipsilateral leg in 20–25 % of all cases.

A specific pattern of injury is the "floating knee." It is a combination of a distal femoral fracture with a proximal tibial fracture and occurs in 5 % of distal

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femoral fractures [12, 13]. Related concomitant vascular or nerve injuries, although rare, have to be excluded in these cases. A common pathogenic mechanism in car accidents is the so-called "dashboard injury," in which the patella is driven by the impact of the knee like a wedge between the femoral condyles. This explains the concordance of injuries between intraarticular distal femur fractures and patella fractures. If the leg is fully extended while a trauma occurs in the longitudinal axis, the tibial plateau is driven against the condyles, resulting in a supracondylar femoral fracture, followed by impaction of the condyles through the femoral shaft. This accident mechanism is common in a fall from height but can also be seen in traffic accidents.

The second peak age is found in mostly elderly female patients between 60 and 75 years of age. This increases the incidence of distal femur fractures up to 170/100,000 population for the over 85 years old [14]. The causes of accidents found in this population are predominantly low-energy trauma. Favorable to this fracture origin is an osteoporotic bone structure.

22.3 Diagnostic

Most distal femur fractures can be diagnosed clinically. A systematic clinical examination should include a vascular and sensorimotor status. If the vascular status of the leg is uncertain, a Doppler ultrasound can be used in the first instance to gain more information. In urgent cases with obvious vascular injuries, an on-table angiography in the operating theatre can be performed without causing extensive delay. In cases without immediate risk to the limb and more subtle signs of a vascular injury, a formal angiography can be performed. The investigation of knee stability is to be omitted in the initial diagnosis because of unnecessary pain provocation and the risk of fracture dislocation, as well as vascular and nerve damage, but should be done intraoperatively after the fracture has been addressed.

After the first clinical examination, radiological diagnostics include conventional X-ray images of the entire femur in two planes and possibly a sufficiently objective radiograph of the distal femur. For intraarticular fractures, additional knee X-rays in two planes should be requested, particularly when no computed tomography (CT) is available.

In the case of intraarticular fractures, a CT with two- and three-dimensional reconstruction are mostly performed for surgical planning. The indications for MRI examination include the diagnosis of additional ligament lesions to the knee or certain intraarticular fractures (rather monocondylar shear fractures).

For further planning of the treatment, the severity of the accompanying soft tissue damage and additional injuries define the treatment plan, including timelines and approaches. In the case of an open fracture and soft tissue injury, the principles of open fracture management should be considered; often, a two-stage procedure will be carried out. Furthermore, the possible development of a compartment syndrome must be observed closely and treated if necessary.

22.4 Classification

There are various different classification systems available for distal femoral fractures, but over the last years the AO classification has become widely used and accepted for clinical, education, and research purposes. The advantage of this classification is a precise mapping of the fracture types and a forecast of therapeutic approach and prognosis [15, 16]. The five-digit alphanumeric code, based on extensive evaluation of a fracture, comprises the fracture location and type. The classification incorporates the division into extraarticular (type A), partially or unicondylar articular (type B), and articular fractures (type C). From A to C, the severity of the fracture increases with worsening of the prognosis for uncomplicated healing.

22.5 Strategies in Distal Femur Fractures

22.5.1 Nonoperative Management

Most of the distal femur fractures are managed surgically due to a more reliable clinical outcome and the option to mobilize the patients more rapidly. The conservative treatment of distal femur fractures in adults is an exception and is only indicated in some patients with nondisplaced fractures, in the presence of severe osteoporosis, or in patients with an extreme high risk of reaction to the general anesthetic.

22.5.2 Operative Management

The surgical treatment of distal femur fractures can be quite demanding and requires a good understanding of the anatomy of the distal femur. The decision for timing of an operation should be carefully considered, depending on the patient's clinical situation and the surgeon's capacity. In complex cases, an external joint-bridging fixator provides excellent temporary stability of the fracture while the planning for the definitive surgery can take place.

When selecting the appropriate surgical procedure, the surgeon is influenced by a variety of factors, such as the type of fracture, associated injuries, bone quality, the surgeon's own experience and that of the surgical team, and logistical requirements. Preoperative planning is mandatory for the appropriate selection of the approach, choice of implant, and to gain an understanding of the fracture characteristics.

Various implants are available for the surgical treatment of distal femur fractures. Nevertheless, the treatment goal remains always the same, regardless of the surgical technique and the implant used. The aim is to achieve anatomical reconstruction of the articular surface and a stable correct axial alignment, rotation, and length of the joint block to the shaft to allow early functional, plaster-free treatment of the injured limb.

Extraarticular distal femoral fractures can be treated with either extra- or intramedullary implants. In both processes, the fracture is reduced and stabilized indirectly, preferably via minimally invasive techniques. Partial intraarticular fractures are usually stabilized with screw fixation and occasionally with additional buttress plates. Simple intraarticular fractures can be treated using extramedullary and intramedullary stabilization, but it has been shown that complex C3-type fractures are more suitable for extramedullary devices, particularly locked plates. The key to deciding which technique to employ is whether the implant can be securely anchored in the distal fragment as well as, to a certain extent, the surgeon's choice based on experience.

22.5.2.1 Approaches to the Distal Femur

The approach to the distal femur is based on the fracture patterns as well as the soft tissue damage. In case of an open fracture, the wound must be appropriately debrided and most likely becomes part of the approach to avoid further soft tissue damage or narrow skin bridges between approaches.

The approach must serve the purpose to address, on one hand, the visualization and reduction of an intraarticular fracture as well as to apply the implant to stabilize the fracture.

Lateral Approach to the Distal Femur

For extraarticular fractures, a lateral approach to the distal femur can be used to apply an extramedullary device without the need to visualize the joint. In this case, a lateral incision of about 8–10 cm is made starting from Gerdy's tubercle. The fascia lata is incised and the muscle vastus lateralis is gently mobilized ventrally to obtain access to the lateral aspect of the femur. There is no need to open the joint capsule in extraarticular fractures, but visualization or palpation of the anterior femur condyle might be helpful for positioning of the plates. Depending upon how extensively the approach must be done proximally, the perforantes vessels have to be ligated.

Parapatellar Approach

The parapatellar approach can be used for all displaced articular fractures of the distal femur, providing a good view of the articular surface. The skin incision is made parapatellar on the lateral side. With a longitudinal extension of the quadriceps tendon and the joint capsule, the patella can be dislocated medially and ensures an optimal overview of the articulation. Through the same approach, the plate can be placed to the lateral aspect of the femur.

Retrograde Approach

A longitudinal skin incision of about 3 cm is made just distal of the inferior patella pole directly over the patellar tendon. The patellar tendon is gently retracted laterally to allow the guide wire insertion to the distal femur. Care should be taken when placing the guide wire, as several anatomical structures are at risk (e.g., posterior cruciate ligament). The guide wire should be inserted in line with the femur axis ventral of the roof of the intercondylar notch (Blumensaat line) under radiographic control.

22.5.2.2 Patient Positioning

In most cases, the patient is placed in supine position on a radiolucent table to allow complete radiograhic imaging of the lower leg up to the hip joint during the surgical procedure. The length of the leg and the rotational profile of the contralateral extremity should be examined preoperatively to ascertain the correct rotational profile and length of the injured femur. Preparation and draping should allow free moving and complete exposure of the operated femur up to the hip joint, especially in cases where a longer plate is to be used. Sterile drapes can be placed under the knee to allow some flexion (about 45°) of the knee to facilitate the reduction of the distal fragment (to counteract the tension of the gastrocnemius muscles pulling the distal fragment into recurvature).

22.5.2.3 Fracture Fixation of Distal Femur Fractures

External Fixation

The definitive treatment of a distal femoral fracture with an external fixator is an exception. In most cases, the fixator is for primary care in severely injured patients where a definitive fracture fixation cannot be achieved due to the accompanying injuries of the patient. Other reasons include the complexity of the fracture or severe soft tissue damage. In fractures with vascular injury requiring surgical therapy, the rapid fixator assembly allows for urgent vascular repair and undisturbed revascularization. The advantages of external fixation are the comparatively low surgical trauma, quick operation time, and simple installation, which can even be made in individual cases outside of regular operating rooms. Disadvantages of external fixation devices are the possibility of pin-tract infection, which occasionally delays the delivery of secondary definitive surgery. The application of external fixation to the distal femur is predominately done as a joint-bridging assembly depending on the size of the distal fragment. For solely femoral stabilization, two Schanz screws are anchored in the distal fragment. The disadvantage in anchoring of Schanz screws in the distal fragment is the risk and the ability to cause a pin-tract infection in the operative field for the definitive surgery. Therefore, the usual fixation of a distal femur fracture is a trans-panning fixation with Schanz screws implanted in the tibia (Fig. 22.1).

Screw Fixation

The isolated screw fixation is the ideal treatment for unicondylar fractures (B-fractures). However, in complex fracture patterns in elderly patients with osteoporosis, the screw fixation might not be sufficient because of the increased strength of the osteoporotic bone. In these cases, additional plate fixation methods are necessary to stabilize or buttress the condyle.

Plate Fixation

Plate fixation methods of distal femur fractures can be used in extraarticular as well as intraarticular fractures. The surgical approaches for plate insertion depend on whether an articular fracture requires open reduction. In extraarticular fractures and fractures with simple articular involvement, a lateral approach to the distal femur is used. Reduction is usually performed indirectly. Larger fragments can be reduced with a Kirschner wire. Especially with multifragmentary A3 fractures, the temporary use of an external fixator or distractor to correct axial alignment and to control the rotation may be required. For displaced intraarticular fractures, a parapatellar approach is recommended to ensure an optimal overview of the articulation.

The articular reconstruction is mostly secured with independent 3.5-mm lag screws, or in simple articular fractures occasionally with large cannulated screws. The stabilization of the metaphyseal fractures extension is preferably achieved with angle-stable implants such as condylar blade plate, dynamic condylar screw (DCS), or locking plates. Despite the advantages of internal fixation, all the devices have disadvantages. Blade plates are technically demanding and require an invasive insertion technique, and the implantation of DCS removes a large amount of distal bone stock.

Locking plates are easier to handle and have overcome the disadvantages of the older plates. These more modern plates have multiple fixed-angle screws providing a good stability – especially in more complex fracture patterns or in osteoporotic bone structure. Most of the locking plates can be used with insertion guides to allow minimally invasive surgical technique with closed indirect reduction of metaphyseal fragments.

The advantages of the locking plates compared to the DCS and the blade plate leads to a favorable use of the locking plates for the treatment of distal femur fractures.

Locking Plates (Internal Fixators)

Locking plates are angle-stable systems that differ fundamentally from conventional plates. The advantage of locked plates is the permanent angle stability with a low risk of screw loosening leading to a secondary loss of reduction. The locking mechanism furthermore facilitates a minimally invasive surgical technique and the preservation of cortical perfusion, while not using compression forces under the plate. The angular

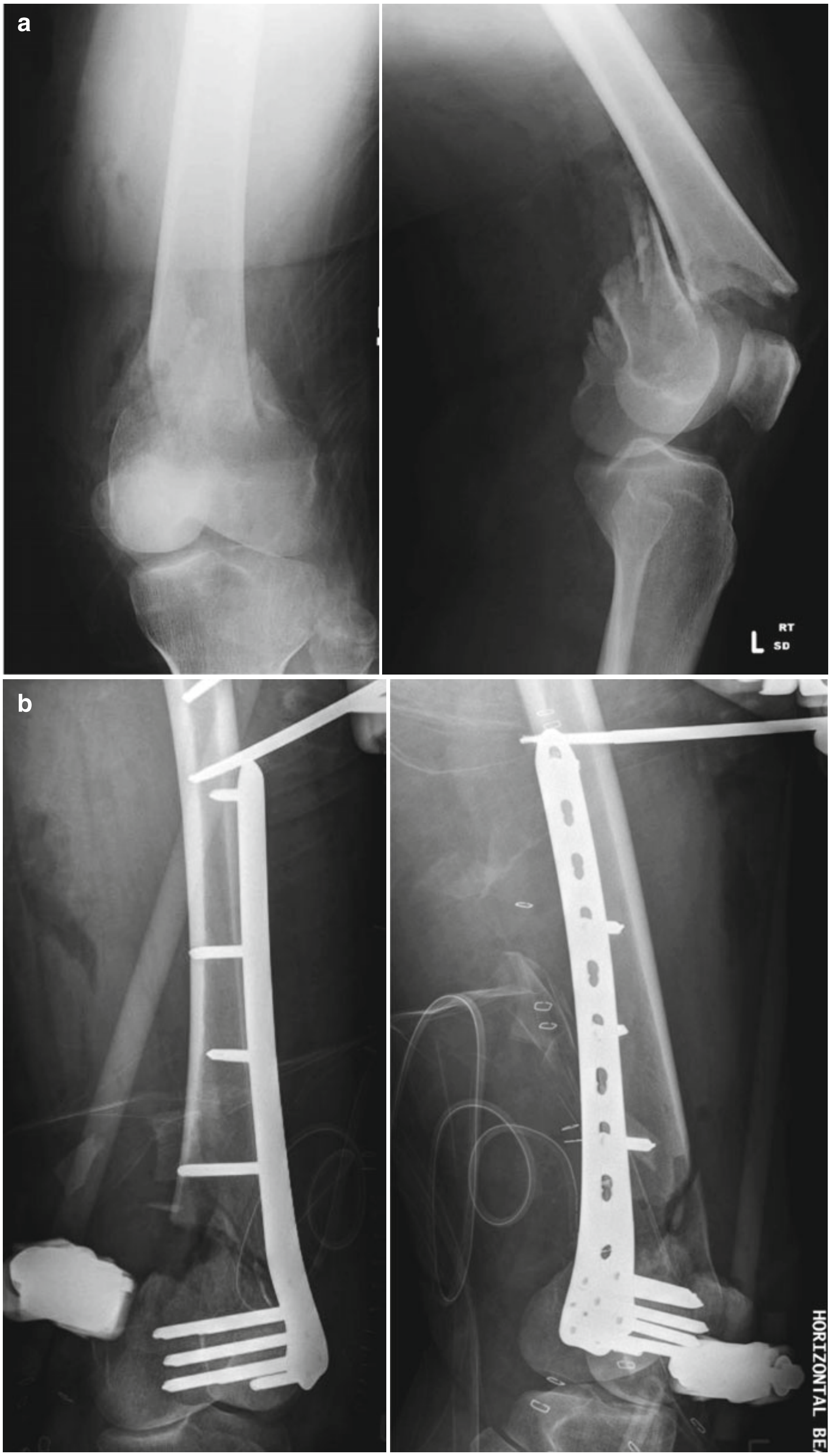

Fig. 22.1 (**a**) A 47-year-old female was caught between two cars, with crushing injury of the left thigh (IIIb open 33.A3 with bone loss). On day 1, the patient underwent a washout and debridement of the wound with application of a knee-spanning external fixator. (**b**) On day 3, the patient had further washout and open reduction with internal fixation with lateral bridging locking plate (LISS plate). The medial wound was partially closed, with application of vacuum dressing. Ex-fix was reapplied at the end of the procedure until complete closure of the wound with secondary skin graft. Seven months later, the patient underwent bone grafting with the RIA system (harvesting from contralateral femur) to address the bone defect, combined with an open arthrolysis of quadriceps tendon adhesions. (**c**) Eighteen-month follow-up X-rays show that the bone defect has bridged and an acceptable clinical function with extension/flexion of 0/0/110°

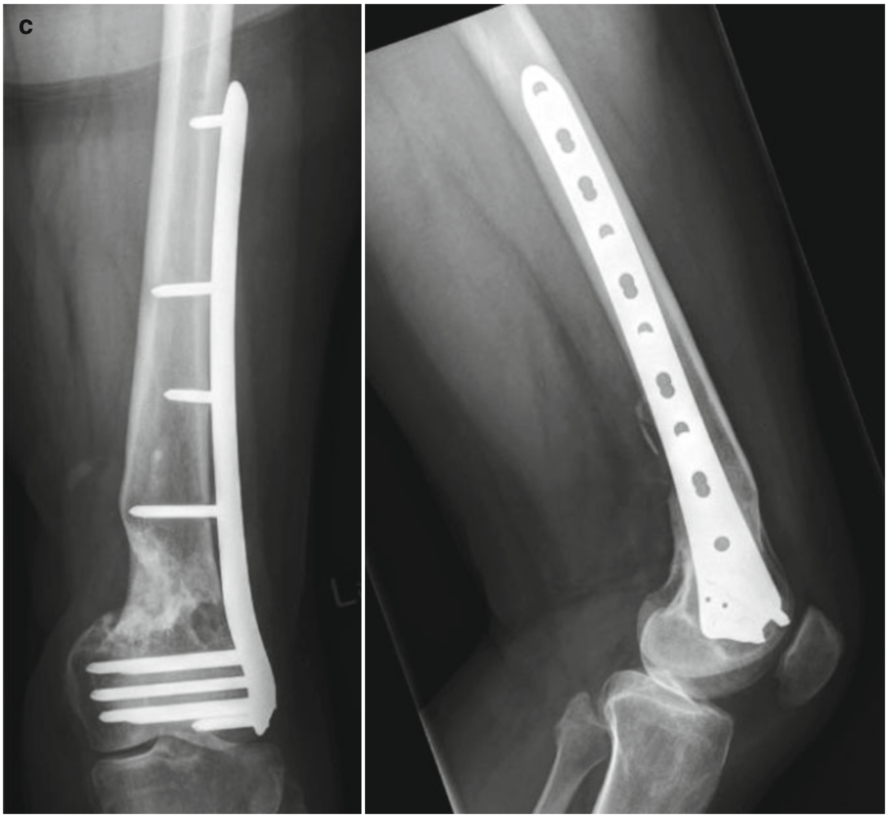

Fig. 22.1 (continued)

stability is guaranteed by the precisely fitting threaded connection between screw head and plate hole [17–19].

The stability of the conventional plate fixation is generated by friction under the plate. The friction force depends on the friction coefficient of the plate pressure, caused by the screw force acting in an axial direction. Thus, in conventional plate fixation with axial extension, a cross-loading of the bone and a longitudinal stress on the screws will occur. With locked plating, the longitudinal forces are transferred through the angle screws as shear forces on the bones and a friction fit is no longer necessary. The result is that most of the cortical blood flow remains undisturbed. This concept is a longitudinal stress of the bone [20].

Specially developed locking plate systems for the distal femur are broadly available, combining angular stability and options for percutaneous plating/screw placement. The LISS (Less Invasive Stabilization System), as the first available system, consists of preformed plates according to the anatomy of the distal femur, ranging up to 19 holes in length. Using the insertion handle, the LISS plate can be implanted minimally invasively, while it acts also in combination with a trocar system for percutaneous insertion of the self-drilling and -tapping locking screws.

In preoperative planning, the implant length is determined, and following the biomechanical principles of bridge plating, the implant is chosen to be rather long. The length of metaphyseal screws as well as bicortical screws in the shaft is directly measured.

A meta-analysis of 268 fractures showed an average infection rate of 3.3 %, a rate of delayed fracture healing and nonunion of 2.4 %, and a rate of implant failure of 5.9 % when using locked plates [17, 21, 22] (Fig. 22.2).

Intramedullary Nailing

Antegrade and retrograde femoral nails can be used for the treatment of distal femoral fractures, depending on the size of the distal fragment. In most cases, retrograde nailing is the first choice for the treatment of distal femur fractures when considering nailing. Advantages of retrograde intramedullary nailing include minimally invasive insertion techniques, decreased blood loss, easier patient positioning for the

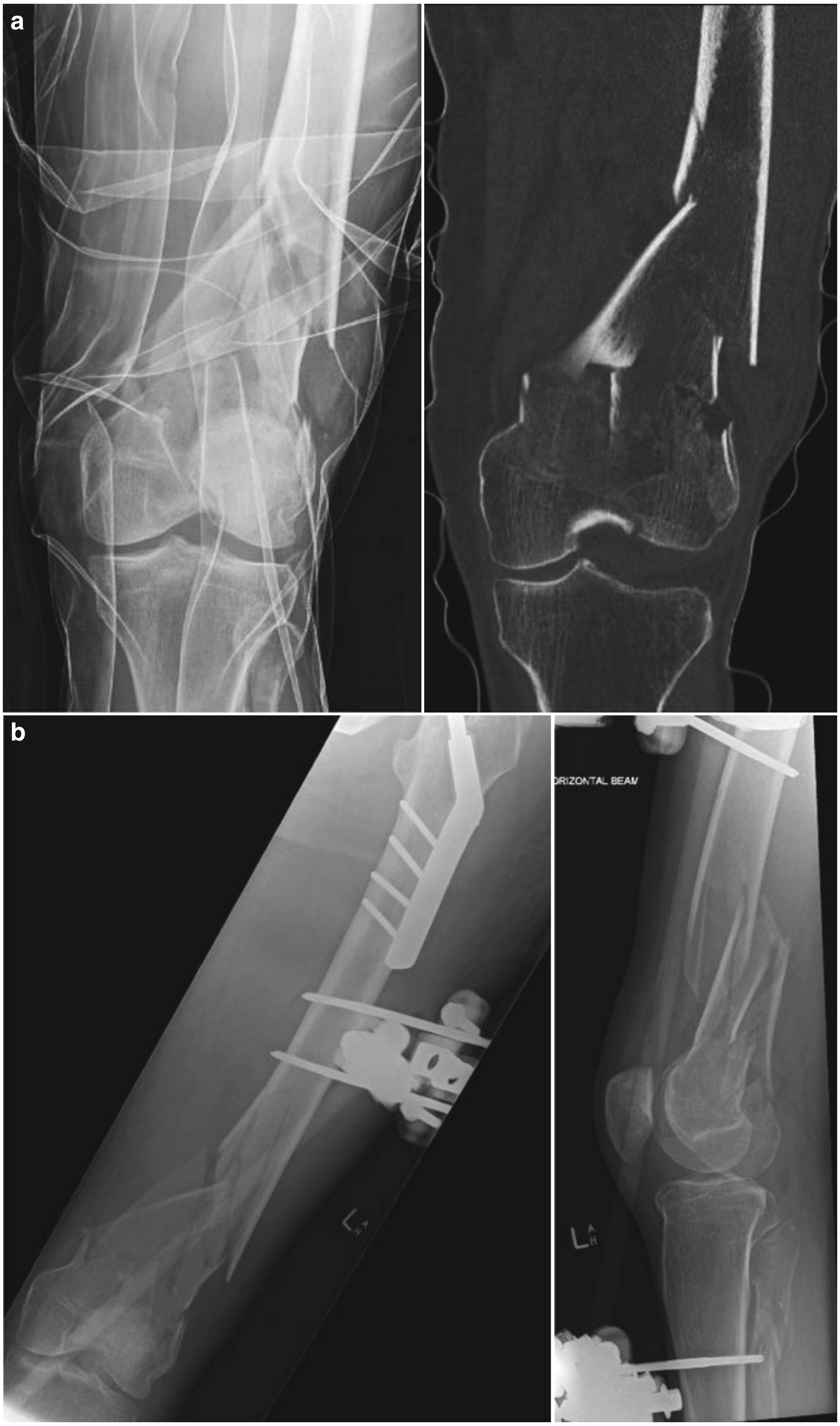

Fig. 22.2 A 72-year-old male had a collision as a pedestrian versus MVA. He sustained a closed 33.C3 distal femur fracture and an ipsilateral midshaft tibia shaft fracture in addition to chest trauma (**a**). Initial management with an external fixator (**b**). Intramedullary nailing for the tibia fracture and a minimally invasive stabilization with a locked plate after open reduction of the joint and fixation with 3.5-mm screws. The patient had sustained previously an intertrochanteric femur fracture, and a dynamic hip screw had to be removed to obtain sufficient proximal plate fixation (**c**). One-year follow-up X-rays demonstrate good callus healing without further intervention (**d**)

Fig. 22.2 (continued)

procedure, and a more reliable locking in the distal fragment than with antegrade nailing. An advantage of nailing distal femur fractures is less frequent irritation of the iliotibial band compared with extramedullary devices.

Despite the benefit that the nail sits central in the axis of the bone, a biomechanical disadvantage is the lower rotational stability of nails compared with extramedullary angular stable implants. Nevertheless, the lower rotational stability appears to be sufficient for postoperative neutralization of torsional forces, considering the good clinical experience with intramedullary stabilization of femoral shaft fractures [23]. Furthermore, intramedullary nails have limited use in C3 multifragmentary articular fractures and in the case of periprosthetic distal femur fractures [24, 25].

Most interlocking nails, by design, achieve rotational stability in the sagittal plane by introducing two distal locking screws, or special locking options like spiral blades in retrograde nails. However, stabilization can be quite challenging in short distal fragments.

Antegrade Technique

Antegrade intramedullary nailing of distal femoral fractures is a rare indication. Standard implants are used, and the indication for extra-articular fractures is limited to those in which the fracture line is at least 4–5 cm proximal to the former growth plate (basically rather distal femoral shaft fractures) [26]. The indication for antegrade nailing was extended by some authors to intraarticular fractures of the distal femur [27, 28]. Intraarticular fractures are reconstructed anatomically according to the articular surface and stabilized with lag screws and a nail placed in a standard antegrade technique. The known general problems of antegrade nailing, such as Trendelenburg limp and heterotopic ossification at the insertion site, join the problematic alignment of the distal fragment. In an analysis of 57 cases of antegrade intramedullary nailing of distal femoral fractures, the infection rate was 0 %, the delayed healing of bone fractures 3.5 %, 0 % nonunion rate, and the rate of implant failure was 3.5 % [27, 28].

Retrograde Technique

Intramedullary nailing of distal femoral fractures is mostly performed in the retrograde nailing technique [29]. For retrograde nailing today, a multitude of different implants are available, differing in material and design (especially regarding the locking options).

The retrograde intramedullary nailing can be performed minimally invasively and allows, in contrast to antegrade nailing, the direct visualization of the articular surface. Indications for retrograde nailing are extraarticular distal femur fractures and simple (C1 or C2) intraarticular fractures of the femur, allowing a double distal locking. A problem is the retaining force of the distal locking screws, which can lead to a loosening in osteoporotic bone. This loosening occurs in about 8 % of cases [23, 30]. The holding force of the distal locking screws could be increased by a modified geometric arrangement of the screws, through the introduction of a spiral blade, and with fixed-angle distal clamping [31]. Other potential problems occurring with the retrograde femoral nailing technique include heterotopic ossification, fractures of the locking pin, adhesion-related limitations of range of motion, swelling of the knee joint, and symptomatic, prominent distal locking bolts [4, 23, 31].

An analysis of 344 distal femur fractures that were treated with retrograde nailing showed an infection rate of 0.3 %, a delayed healing rate of 4.7 %, a nonunion rate of 2 %, and an implant failure rate of 8.4 % [32–36]. Rotational deformities were found in 8.3 % and deformities in the frontal plane in 3.2 % of cases (Figs. 22.3 and 22.4).

22.5.2.4 Postoperative Care and Rehabilitation

The follow-up treatment of distal femur fractures needs to be adjusted to the individual fracture situation, the surgical treatment, the implants being used, the concomitant injuries, and the cooperation of the patient. The wounds should be checked regularly and the suture materials should be removed after about 12 days post operation. After every operation, an X-ray examination in two planes should be performed for the purposes of documentation and legal formality. The surgeon should keep records about the maximum range of motion, the degree of weight bearing, and the need for additional support (e.g., ortheses). Special attention should be paid to thrombosis prophylaxis and providing sufficient pain medication to allow postoperative rehabilitation. On the day after the operation, treatment with active and passive physiotherapy (continuous passive motion, CPM) should immediately start, to reduce the risk of adhesions, support the cartilage healing, and to help to reduce the swelling [37]. It is particularly important to gain the full knee extension back early on. The CPM treatment should be performed frequently, until the patient becomes mobile.

Fig. 22.3 A 42-year-old female patient with floating left knee injury (IIIb open C3 distal femur fracture with bone loss and closed 42.B2 tibia fracture). Initial stabilization in a regional hospital with nailing of both fractures on the day of admission (**a**). Presentation to our output clinic 6 weeks postsurgery with ongoing pain and loosening of the distal locking bolts (**b**). Removal of nail and restabilization with a locking plate. The bone defect was simultaneously bridged with cortical bone struts harvested from the pelvis (**c**). After 6 months, regrafting of the proximal (shaft) section. Solid consolidation 1 year postsurgery with good, stable function of the leg; clinical pictures from two different time points (**d**)

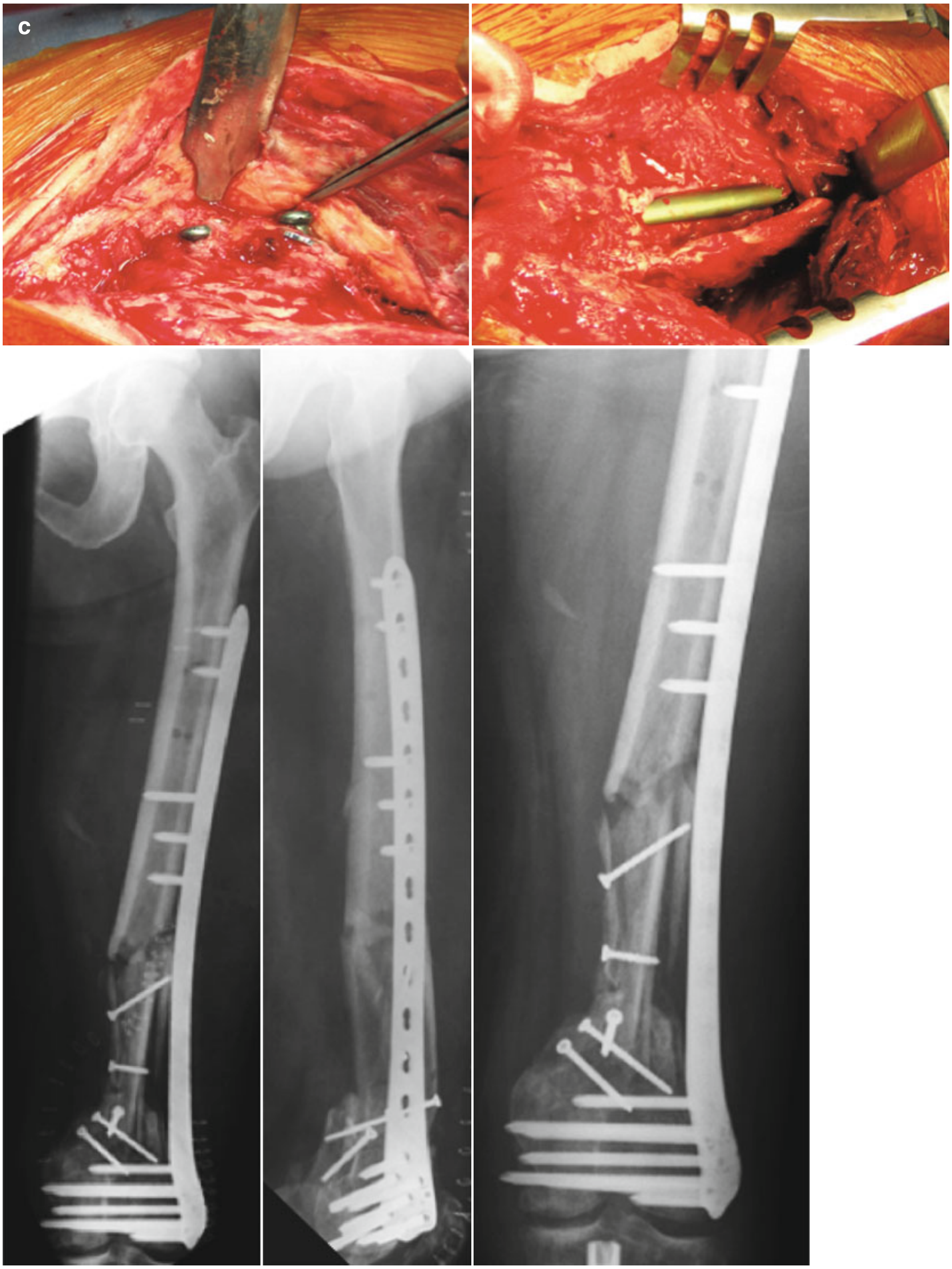

Fig. 22.3 (continued)

Fig. 22.3 (continued)

Depending on the fracture type, patients will partially weight bear for 6–12 weeks. Extraarticular fractures need partial weight bearing for 6–8 weeks, whereas complex intraarticular fractures might need partial weight bearing for up to 12 weeks. Depending on the radiological signs of bone healing, the weight bearing can be increased stepwise. In general, the postoperative management should include individual circumstances and must be well explained to the patient.

Implant removal can normally be considered after 18–24 months, if necessary.

22.5.2.5 Complications

The challenge of nonoperative treatment is to maintain the correct fracture alignment and, therefore, maldeformity is a rather frequent complication. Particularly in the elderly, the fracture heals less reliably and pressure sores or even soft tissue break-down due to plaster management are not uncommon.

Complications with operative treatments include general risks of damaging neurovascular structure and the risk of infection. The surgeon should pay special attention to the vascular bundle that runs closed posterior to the knee joint, especially when drilling in the anterior posterior direction to restore complex fractures. Particularly in multifragmentary fractures, a malalignment of the distal fragment can occur if the implant is not placed accordingly. The positioning of the implants and the intraoperative control of axis and length are even more important in minimally invasive treatment. In addition to the general postoperative complications, the loss of reduction and a reduced range of motion in the knee joint might occur after distal femur fractures. The infection rate after surgical

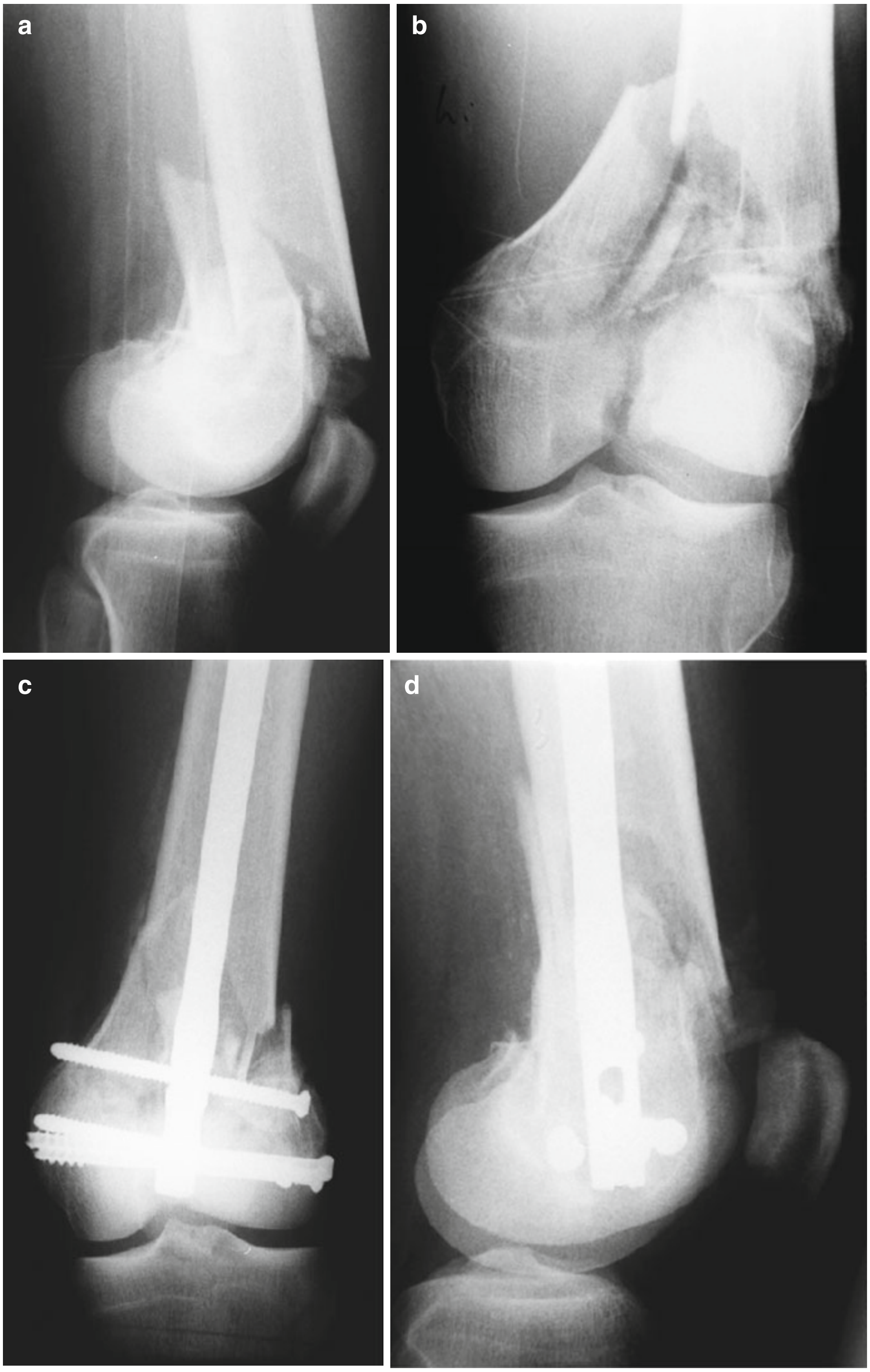

Fig. 22.4 Distal femur fracture after an accident (AO-Classification C 2). X-rays of the day of accicdent (**a**, **b**). Reconstruction of articular bone block with a lag screw and distal femoral nail. The x-ray 6 weeks postoperatively show a good reduction with beginning bone healing (**c**, **d**)

treatment of distal femur fractures is about 3.9 %, depending on the soft tissue damage, the patient's general condition, the surgical technique, and the implant used [23, 30, 34]. A delayed union occurred in 5 % of the cases, a nonunion only in 2.2 %, and implant failure was reported in up to 6.4 %. Arthritis is another common late complication, either due to malalignment of the axis or cartilage damage in case of intraarticular fractures. Therefore, the identification and early treatment of malalignments are important. Instability of the knee joint after distal femur fractures has an incidence of up to 39 %, and a limitation of the range of motion at the knee joint between 10 and 40 % [38, 39]. In addition to intensive physiotherapy to achieve a better range of motion, operative mobilization under general anesthesia should be considered in some cases.

Conclusion

Distal femur fractures occur both in young patients following high-energy impact, often resulting in comminuted and open fractures, and in elderly patients with osteoporotic bone and resulting low-energy injuries. The treatment of distal femoral fractures is mostly performed using locking plate techniques and, to a lesser extent, retrograde intramedullary nailing. Both operative stabilizing systems follow the principle of biological osteosynthesis. The key factors of the operative treatment are the reconstruction of the articular surface and restoring the correct biomechanical axis of the femur. The surgical management of distal femur fractures remains challenging and requires accurate preoperative planning, including a compulsory CT scan if the articulation is involved. With proper planning and treatment, good long-term results after open reduction and internal fixation can be achieved. Knee function increases over time, but the range of motion does not increase after 1 year. The development of secondary osteoarthritis in complex articular distal femur fractures does not necessarily mean a bad long-term outcome, as long as the femoral axis is correct [40].

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Patella Fractures

23

Hans-Jörg Oestern

23.1 Anatomy

The patella is a sesamoid bone that connects the quadriceps tendon and the patella ligament. Medially and laterally, the patella is supported by the retinacula. Biomechanically the patella shifts the lever arm anterior and increases the extension power of the quadriceps muscle up to 50 %. In downhill walking, the pressure on the femoropatellar joint increases from 3.3 to 7.6 times. Therefore, the demands on the osteosynthesis are very high.

23.2 Epidemiology

Patella fractures account for about 1 % of all fractures. They are most common in people who are 20–50 years old.

23.3 Diagnosis

History with fall on the flexed knee, pain, hemarthros, and diminished active extension indicate a patellar fracture. Even with ruptured retinacula, there is a little extension power left due to the iliotibial tract and the adductors.

X-rays in two planes and the tangential view will clarify the fracture diagnosis. In case of conservative treatment, MRI can verify chondral or osteochondral lesions and the degree of soft tissue damage.

In 1–2 % of all people, a bipartite patella is found, which should not be confused with a fracture. It is often on both sides, on the lateral superior side with a round sclerotic margin.

23.4 Classification

Patellar fractures can be classified regarding their trace as transversal, apex, basis, comminuted, vertical, and osteochondral. Transversal fractures are the most common and account for 50–80 %, followed by comminuted (30–35 %) and vertical fractures, with 12–17 %. The AO classification distinguishes between A type (extraarticular), B type (partial articular), and C type (total articular and comminuted).

23.5 Treatment

23.5.1 Conservative

Nondislocated fractures with an intact extensor mechanism can be treated conservatively. The preserved extensor mechanism can be proved by extension ability of the knee joint. This is more so in longitudinal fractures than in nondisplaced transverse fractures, where often the retinacula are torn. Conservative treatment should be functional with the security of an orthesis. Limitation of flexion should be 30° and then 60° after 3 weeks. Extraarticular nondisplaced fractures can be treated immediately functionally.

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23.5.2 Operative

23.5.2.1 Indication

Fractures with gaps and steps in the articular surface

23.5.2.2 Approach

Either a transverse or a longitudinal incision is possible. The transverse incision gives the best cosmetic result. A midline longitudinal incision allows the extension proximally and distally and a medial approach for intraarticular revision, if necessary. Also, a lateral parapatellar approach is possible with little danger of injuring the infrapatellar branch of the saphenous nerve. The extensor mechanism is identified after incision of the superficial fascia and tears are repaired [1, 2].

23.5.2.3 Technique of Reduction and Tension Band Fixation

Larger fragments are best reduced with a large-pointed reduction forceps. The position of the knee for reduction is in extension or hyperextension. Reduction quality of the articular surface is palpated from the inside of the joint. For tension band wiring, two parallel K-wires (diameter 1.8–2.0 mm) are drilled parallel through the reduced fragments, or prior to reduction, the K-wires are drilled from the fracture side into one fragment and, after reduction, into the other fragment. The K-wires should be placed in the middle of the patella or 5 mm dorsal of the anterior cortex. The cerclage wire (1.0–1.2 mm) is placed through a curved large cannula directly on the bone through the ligamentous structures. A figure of zero or eight is possible. A figure of eight is more stable against torsion forces. While tightening the cerclage wire the reduction is controlled by an image intensifier and palpating manually. After tightening of the cerclage wire, the K-wires are bent 180° and are driven to the bone through a small incision in the quadriceps tendon. The distal ends of the K-wires are cut 5–10 mm outside of the bone. Additional fragments can be fixed by screws or additional small K-wires to obtain two main fragments (Fig 23.1) [1, 2].

23.5.2.4 Screw Fixation

In longitudinal fractures, screw fixation is the method of choice either by cannulated or normal 4.0 cancellous screws. Reduction is maintained by a reduction forceps. The screws can often be inserted percutaneously.

23.5.2.5 Patellotibial Cerclage

In lower pole fractures, in addition to transosseous sutures, a patellotibial cerclage is necessary, which is passed through the tibial tuberosity or through the whole of a cannulated screw or around a 3.5 mm screw.

23.5.2.6 Partial Patellectomy and Patellectomy

Whenever possible, patellectomy should be avoided to keep the lever arm intact. In case of a severe comminution in the middle of the patella, an osteotomy can be performed and the two remaining fragments can be fixed under shortening by screws and cerclage wires. If this is not possible, patellectomy has to be performed, leaving as much as possible of the extensor apparatus and suturing it directly together.

23.5.3 Postoperative Treatment

Early motion by continuous passive motion (CPM) is helpful and should be started very early, with up to 90° of flexion. Weightbearing up to 20 kg for 4–6 weeks is allowed. In patellectomy and partial patellectomy, flexion should be limited to 60° with additional support provided by a brace.

23.5.4 Implant Removal

Implant removal should be performed after 1–2 years on average. A patellotibial cerclage wire should be removed after 12 weeks to guarantee full range of motion.

23.6 Complications

23.6.1 Skin Necrosis

Skin necrosis can be avoided by dissecting and preparing between the subcutaneous fascia and the extensor apparatus. Necrosis will be the result of preparing between the skin and the subcutaneous fascia. Long-lasting traction with wound hooks should be avoided.

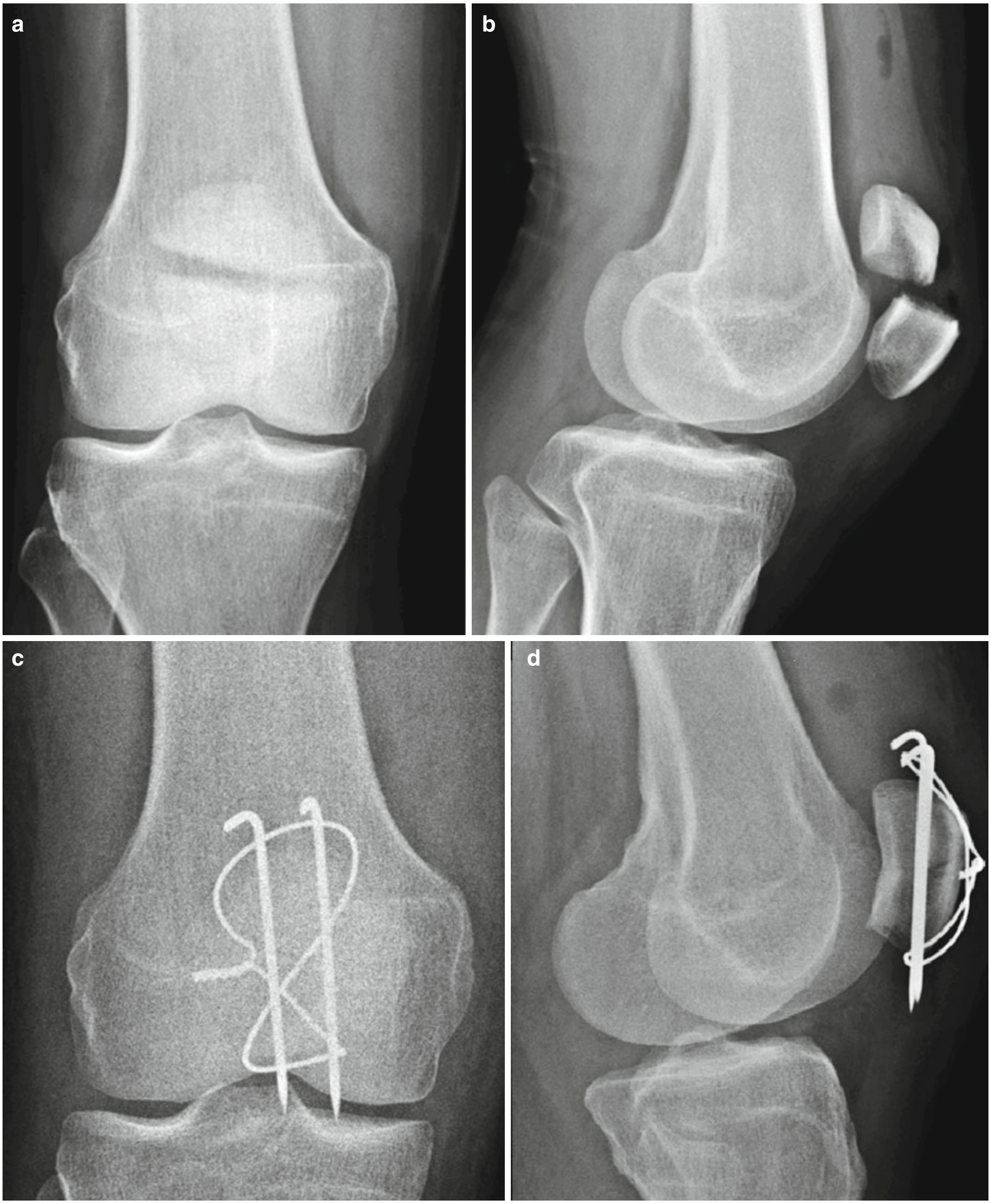

Fig. 23.1 44 year old male Transverse fracture of the patella (**a**, **b**) ,Tension band fixation . fracture has healed 8 weeks after surgery (**c**, **d**)

23.6.2 Infection

Early debridement and irrigation should be performed every 48 h until the specimen is negative. Long-term application of antibiotics is necessary.

23.6.3 Skin Irritation by Wire Tips

Irritating ends of wire tips should be shortened to avoid perforation and possible infection.

23.6.4 Patella Baja

This complication can occur after patellotibial cerclage and is produced by misjudging the exact length of the patellar tendon. The correct length is indicated by the X-ray of the opposite side. In case of patella baja, the cerclage wire should be removed after 6–8 weeks.

23.6.5 Implant Failure

Migration of the wire can lead to displacement and articular incongruity. This complication can be prevented by inserting the 180° bent wires into the bone. In case of articular incongruity and displacement, a reosteosynthesis is necessary [1].

23.6.6 Loss of Motion

As the first step, intensive physiotherapy is necessary. When there is no improvement, arthroscopic-assisted arthrolysis is the next step, along with removing the scarred tissue.

23.6.7 Posttraumatic Arthritis

Posttraumatic arthritis can occur after incongruity of the articular surface, which can be prevented by exact intraoperative palpation of the articular surface and intraoperative X-ray control or CT control. If the patella ligament is attached too far anterior, the patellar pole rotates backwards. This situation should be corrected. In case of multifragmentary fracture with elongation of the patella after healing, patellectomy should be performed.

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Knee Ligament Injuries

24

Philipp Forkel and Wolf Petersen

24.1 Introduction

The knee is stabilized by four major ligaments: the anterior cruciate ligament, the posterior cruciate ligament, the medial collateral ligament, and the lateral collateral ligament. Injuries of these ligaments are frequent because of the increased sports participation in our population.

Knee ligament injuries can be acute or chronic and, in many cases, combined injuries can be observed, such as anteromedial or posterolateral instabilities (Fig. 24.1). The direction allows a first classification of knee instabilities. The severity of these instabilities can be divided into four grades: 0 = no instability, I = slight instability due to partial rupture, II = medium instability with complete rupture, and III = severe instability with two or more ligaments involved.

In recent years, the diagnostic and therapeutic procedures to treat knee ligament injuries have changed. New imaging methods, such as three-dimensional reconstructions of CT scans and MRI slices and sequences, help to complete imaging information. Despite these new imaging methods, the clinical examination of the knee is still crucial. The manual examination provides essential information about the function and the functional stability of the knee.

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24.2 Anterior Cruciate Ligament (ACL)

No single structure in the knee joint has created more interest in the scientific community than the anterior cruciate ligament.

24.2.1 Anatomy

The ACL consists of two functional bundles: the anteromedial bundle (AM) and the posterolateral bundle (PL) (Fig. 24.2). Their tension differs depending on joint position. They show a reciprocal tension pattern. In extension, the PL shows maximal tension. The AM shows maximum tension in flexion. These two bundles stabilize the tibia against anterior translation in different joint positions. Because the PL bundle shows maximal tension during extension, it also plays an important role in providing rotational stability [21].

24.2.2 Trauma Mechanism

The reported incidence of ACL rupture is 1 per 3,500 habitants [9]. The main reasons are accidents in sports. Sports requiring pivoting and jumping, such as soccer, basketball, and handball, are especially high-risk activities for ACL rupture. Alpine skiing should also be mentioned in this context. Many analyses have shown that ACL ruptures are more frequent in female than in male athletes [2, 16, 22].

Video analyses have provided information about the rupture mechanism. According to these analyses, ACL rupture mainly occurs without direct contact with an opponent athlete. The majority of ACL ruptures

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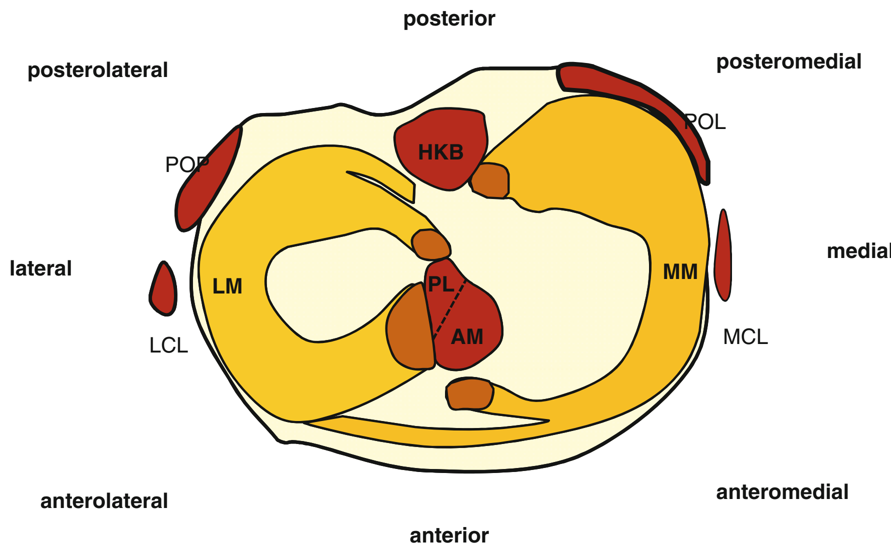

Fig. 24.1 Classification of knee instabilities

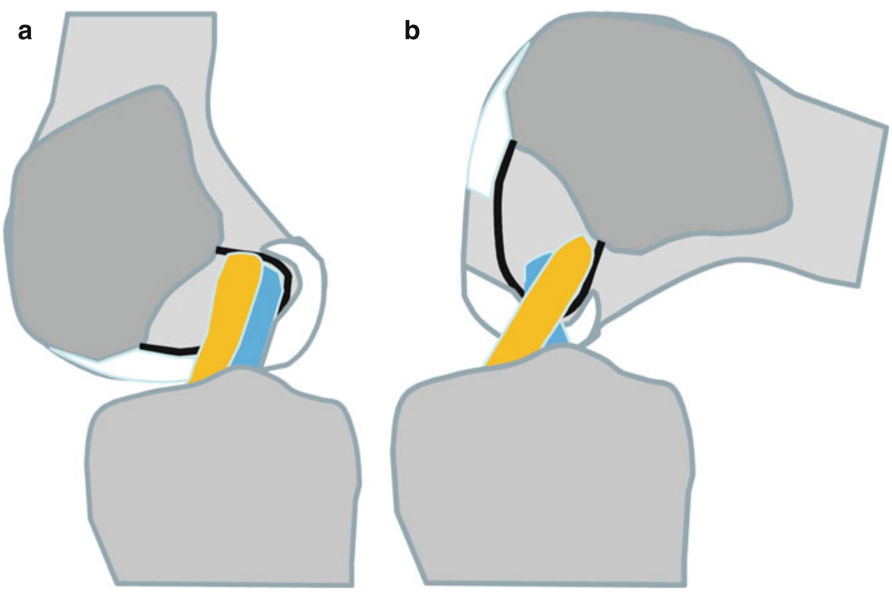

Fig. 24.2 Anatomy of the anterior cruciate ligament. (**a**) The PL bundle is tight in extension. (**b**) The AM becomes tight with flexion

occur in so-called noncontact situations [22]. The most dangerous situations are:

1. Landing after a jump
2. Sudden stops
3. Sudden rotation moves

At time of injury, the body shows a straight position and the knee and the hip are flexed slightly (5–25° flexion in the knee joint). The lower leg is rotated externally and is in a valgus position. These joint positions produce maximal tension on the ACL fibers. Most athletes report a fixed foot at time of injury, so that a rotation of the foot isn't adequately possible. The center of gravity is behind the center of the knee in most cases, and the foot has complete contact with the ground. In that position, the force of the M. quadriceps is strong enough to rupture the ACL. In that position, the hamstrings have an unfavorable arm of lever to protect the ACL.

In alpine skiing injury the mechanisms have also been identified. Most ACL ruptures in skiing occur while the knee is flexed maximally and the center of gravity is behind the knee while the lower leg is internally rotated. In the literature, this mechanism is called the "phantom foot mechanism" [8].

24.2.3 Prevention

Motion analyses reveal women show a straighter landing position after a jump compared with men. The female knee and the hip joint show lower flexion but more valgus position during the landing after a jump. From these analyses, different prevention strategies have been developed in order to reduce incidence of ACL rupture in sports [4, 11, 16, 22, 24]. These prevention strategies might be divided as follows:

1. Education about injury mechanism and modification of dangerous movement patterns
2. Hamstring and hip rotator training
3. Training of proprioception
4. Jump exercises under supervision

Modern prevention strategies combine these four different approaches [17, 23]. They consist of a sequence of exercises that may be integrated into the warm-up phase.

24.2.4 Diagnostics

Most ACL ruptures do not show external signs of injury [26]. Acute ACL ruptures mostly present an extensive hemarthrosis. A puncture of this effusion, however, is only necessary if there is painful tension from the capsule.

The anterior drawer test is a classical test that provides information about anterior instability. Unfortunately, sensitivity of this test in acute ACL injuries is low because of the effect of the hamstrings. The Lachman test is known to be more sensitive (drawer test in 20–30° of flexion that reduces the lever arm of the hamstrings). In case of acute anterior instabilities, the part of positive Lachman test ranges from 78 to 99 % in contrast to the anterior drawer signs with 22–70 % [13]. The Lachman test can be quantified using the KT-1000 Arthrometer. The quantitative Lachman test might be useful for scientific purposes but also for the diagnosis of partial ruptures (Fig. 24.3).

In daily activities or in sports, patients mainly feel unstable when the knee shows light flexion (20–30°) and the foot is fixed in light internal rotation. This mechanism can be evaluated with dynamic anterior subluxation tests, such as pivot shift phenomenon. The pivot shift phenomenon is the most popular dynamic subluxation test. The examiner holds the leg in valgus with internally rotated foot. This produces an anterior subluxation of the lateral tibia plateau. When the knee is flexed, the iliotibial tract reduces the lateral tibia plateau

Fig. 24.3 Lachman test in 20° of flexion

at approximately 30° of flexion. This reduction is visible or palpable as a clicking phenomenon. Other well-known subluxation tests are the Losse test, the Slocum sign, or the jerk test.

Clinical studies revealed that a positive pivot shift test after ACL reconstruction may be associated with poor clinical outcome.

On plain X-rays, the ACL cannot be seen. However, an anterolateral tibial plateau fracture (Segond fragment) is considered to be pathognomonical for an ACL injury. The same is true for the anterior impression fracture of the lateral femoral condyle.

The MRI is a sensitive method to make a diagnosis of ligament injuries and their concomitant injuries. The sensitivity of MRI to identify an ACL lesion ranges from 92 to 100 %, its specificity is 85–100 % [13, 29, 31, 33]. Direct findings of an ACL injury such as disruption or the lack of a ligament signal can be differentiated from indirect signs such as effusion or bone bruises of the lateral femoral condyle or at the posterior tibial plateau. The bone bruise pattern seen in MRI can give important information regarding severity and time from trauma to MRI; this might be important for legal reasons. The MRI does not allow a dynamic functional examination. This is the most important disadvantage of this method. Therefore, the findings in MRI must always be interpreted in relation to the findings of clinical tests (Fig. 24.4).

Computer tomography (CT) should be performed in case of suspicion of an associated tibia plateau fracture. After surgery, the CT scan can provide adequate information about tunnel placement. This method is helpful in case of failed ACL reconstruction to plan revision surgery. It provides information about the width of the tunnel. The three-dimensional CT-scan

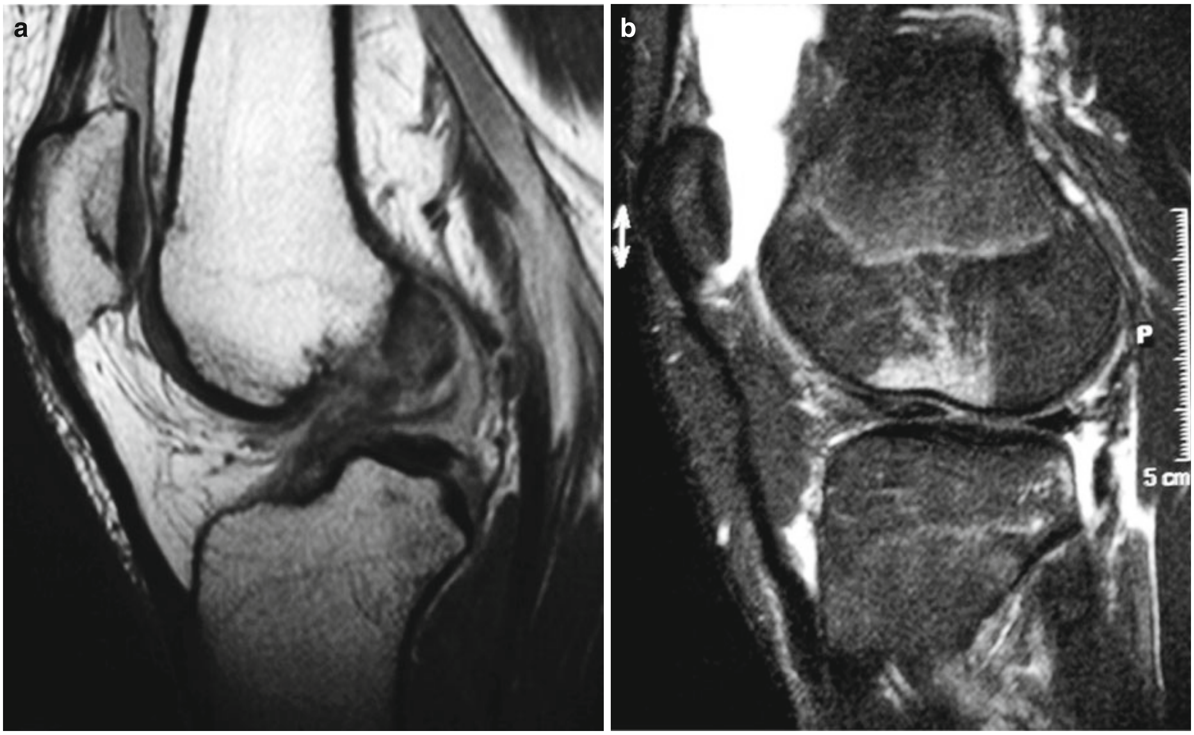

Fig. 24.4 (**a**) MRI showing a proximal rupture of the ACL. (**b**) Indirect signs of an ACL rupture: Anterolateral impression fracture of the lateral femoral condyle and posterior bone bruise at the lateral tibia plateau

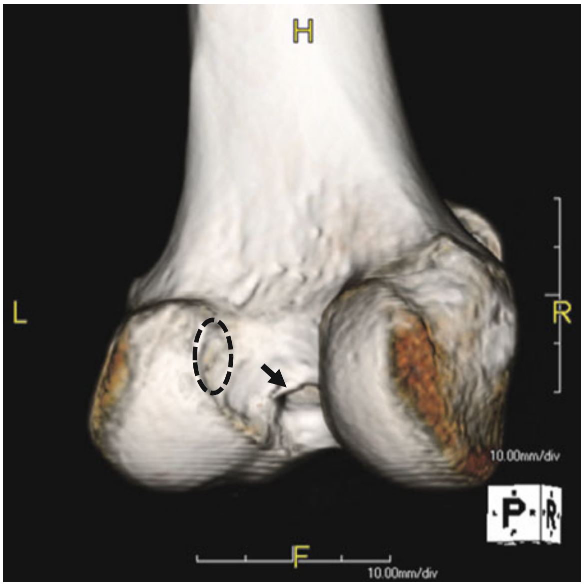

Fig. 24.5 CT scan showing an anterior ACL tunnel at the roof of the intercondylar fossa. The *dotted circle* shows the anatomical position of the femoral ACL insertion. The *arrow* shows the malpositioned ACL tunnel at the roof of the intercondylar fossa.

reconstructions allow a precise identification of the tunnel positions (Fig. 24.5).

24.2.5 Partial ACL Ruptures

The incidence of partial ACL ruptures has been the subject of controversy for a long time [25]. In the meantime, isolated ruptures of the PL and the AM bundle have been described [25]. The rupture of the PL bundle is supposed to occur close to extension; the isolated rupture of the AM occurs in flexed knee position. The diagnosis of isolated ruptures of only one bundle of ACL is difficult. Clinical findings, findings of imaging methods, and arthroscopical findings must be well interpreted. In clinical examination, an isolated rupture of PL may cause a positive pivot shift phenomenon. In most cases of isolated AM rupture, however, the pivot shift sign is negative.

Rupture of the AM may lead to an extension deficit if fibers of the ruptured bundle impinge at the anterior edge of the notch. If there is only a short time between the accident and the MRI procedure, the MRI may reveal edema or a gap in the fibers' continuity in the correlative bundle. The arthroscopical examination and evaluation of chronic PL ruptures are complicated because of relaxation of the PL bundle in flexion. Only acute trauma signs such as hematoma and a discontinuity of PL fibers can give a hint of an isolated PL rupture.

24.2.6 Natural History After ACL Rupture

The loss of ACL may lead to anterior and rotational instability [5]. This instability may impair the patient directly (instability, giving way). In the long-term, an anterior instability can cause secondary damage to the knee joint. A chronic anterior subluxation raises the applied load on the posterior parts of the tibia plateau and the posterior horns of the menisci. The pathological loading on the posterior parts of the tibia plateau and the menisci may be cause for a posteromedial osteoarthritis. Patients with secondary posttraumatic osteoarthritis and ACL deficiency are 15–20 years younger compared to the patients with primary osteoarthritis [28]. This was described by Daniel et al. [5] and was called the “ACL injury cascade.” However, the ACL injury cascade model describes the onset of a posttraumatic gonarthrosis incompletely. Initial injuries (concomitant ligament injuries, damage of cartilage and menisci) are ignored, although they have an important influence on the postoperative results after ACL reconstruction. Anterior subluxation of the lateral tibia plateau may cause lesions of the lateral meniscus such as root tears and cartilage damage (Fig. 24.6). Therefore, we should better speak about the “knee trauma cascade” [27] instead of the ACL injury cascade (Fig. 24.7). Initial lesions of menisci and cartilage may explain findings in clinical studies reporting radiological signs of osteoarthritis after ACL reconstruction. ACL reconstruction can only treat anterior instability but not associated meniscus and cartilage damage.

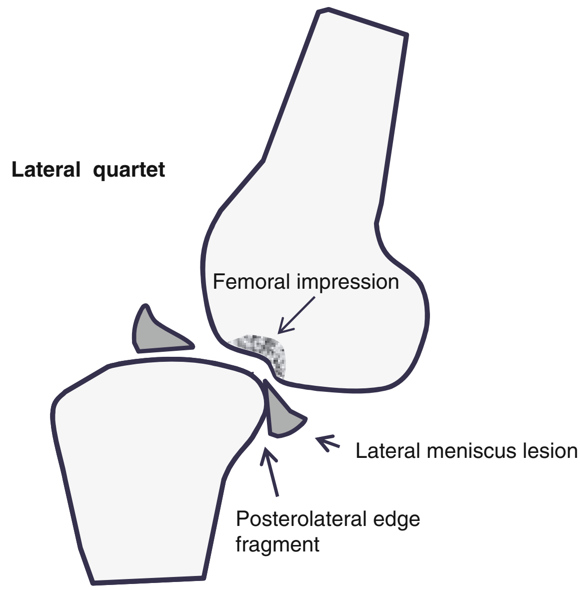

Fig. 24.6 Schematic drawing of the injury mechanism of associated lateral injuries. The so-called “lateral quartet” is the rupture of the ACL, impression fracture of the lateral femoral condyle, posterior bone bruise at the lateral tibia plateau, and injury of the lateral meniscus

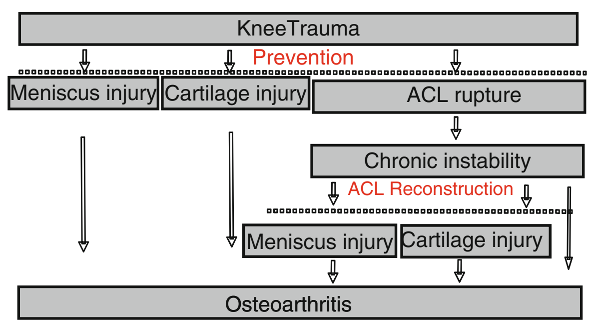

Fig. 24.7 Knee injury cascade

24.2.7 Indication for ACL Reconstruction

A prospective study revealed that reconstruction of the ACL may prevent the onset of secondary intraarticular damage and of degenerative joint lesions in patients with symptomatic instability and risk factors [12]. Risk factors are high activity level, giving way phenomena during sports or daily life activities, and a positive pivoting. Some patients may cope with an unstable knee [7]. This ability is independent from activity level. Different criteria can be used to identify such patients: one leg jump test >80 % of the contralateral leg, more than one giving way phenomenon, impairment of daily activities of less than 80 % due to knee injury and a knee function score < 60 % [7].

The indication for ACL reconstruction remains an individual decision. Patients and athletes showing a symptomatic instability who do not want do modify their activity level are candidates for ACL reconstruction. A concomitant bucket-handle tear of menisci is another indication for ACL reconstruction because of the high rate of menisci re-ruptures in unstable knees. The same is true for secondary intraarticular lesions

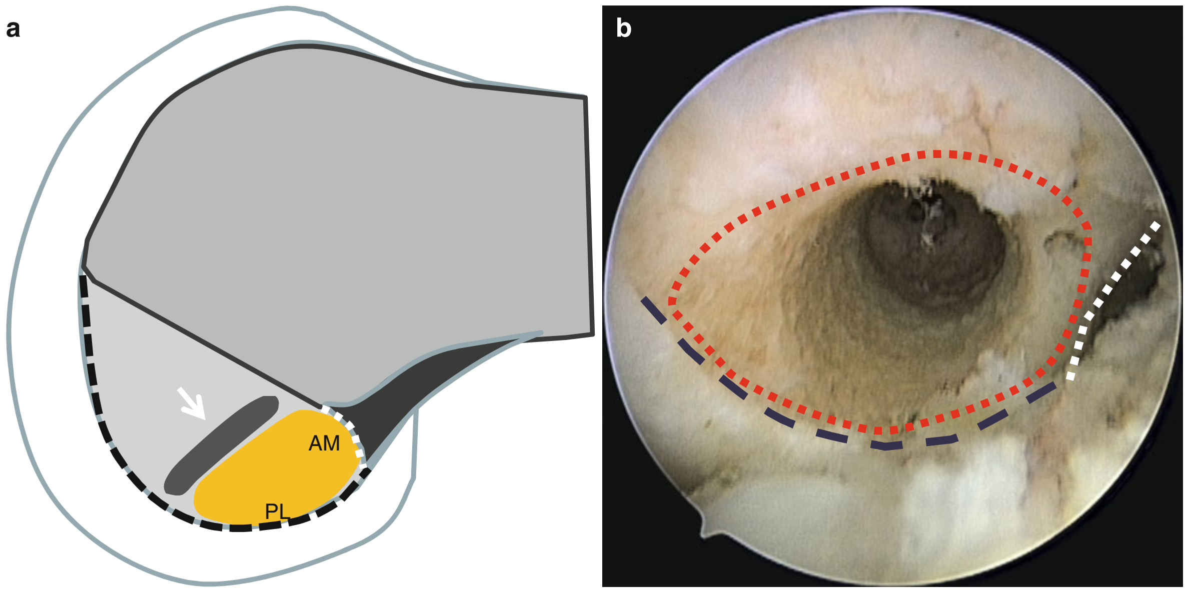

Fig. 24.8 Anatomical ACL reconstruction (**a**) Schematic drawing of the femoral insertion of the ACL (*white dotted line*: intercondylar line, *black dotted line*: cartilage border). The *white arrow* indicates the resident's ridge. (**b**) Anatomical femoral bone tunnel for ACL reconstruction (view from the medial portal) *white dotted line*: intercondylar line, *blue dotted line*: cartilage border, *red dotted line*: anatomical insertion zone of the ACL

due to a symptomatic chronic instability. An age over 40 years is not a contraindication for ACL reconstruction. However, in patients older than 40 years, the prevention of secondary osteoarthritis is less important. In case of concomitant presence of osteoarthritis and varus knee, the indication of high tibial osteotomy (HTO) should be considered. In case of persisting instability, the HTO can be combined with the ACL reconstruction in a one- or two-step procedure.

In children and adolescents with open epiphysis, the indication of ACL reconstruction is still under discussion. Prospective studies revealed a high incidence of secondary posttraumatic lesions in children with a persisting anterior instability due to ACL deficiency [1]. A newer study from Scandinavia showed that some children may develop strategies to cope the anterior instability [14].

If there is an indication for ACL reconstruction, the risk of damage to the epiphysis using a tendon graft without a bone block is very low.

24.2.8 Reconstruction of the ACL

Today, the replacement of the ACL with the use of autologous tendon grafts is the gold standard of operative treatment. The most frequently used tendon grafts are the semitendinosus tendon and the patella tendon. Many studies compared both grafts. The differences in long-term stability were small [10]. The donor site morbidity after harvesting the patella tendon is supposed to be higher than in cases of harvesting the semitendinosus tendon. A further graft option is the quadriceps tendon.

Experience from revision surgery after ACL reconstruction showed that the main reason for graft failure is incorrect placement of bone tunnels. The function of the ACL can only be restored if the bone tunnels match the femoral and tibial insertion zones. The technique, respecting the anatomic landmarks for ACL reconstruction, is called "anatomical ACL reconstruction" [20, 21].

The complete femoral insertion zone of the ACL is difficult to visualize from the classical anterolateral arthroscopy portal. An adequate overview on the wall of the lateral femur condyle is only possible using the anteromedial portal (Figs. 24.8 and 24.9).

The drilling technique of the bone tunnels influences the tunnels' position. When using a transtibial drilling technique, the position of the femoral tunnel depends on the tibial tunnel's position. It has been shown that transtibial drilling tends to place the tunnel closer to the roof instead of the center of the ACL

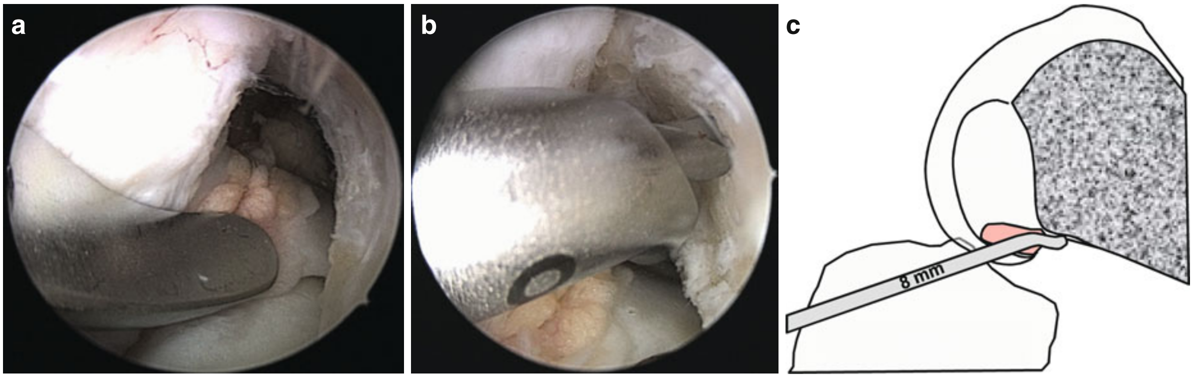

Fig. 24.9 Anatomical femoral tunnel placement via the medial portal. (**a**) Insertion of the medial portal aimer via the medial portal (Karl Storz, Germany). (**b**) The hook of the offset guide is placed behind the Facies poplitea. (**c**) Schematic drawing showing the offset guide in place

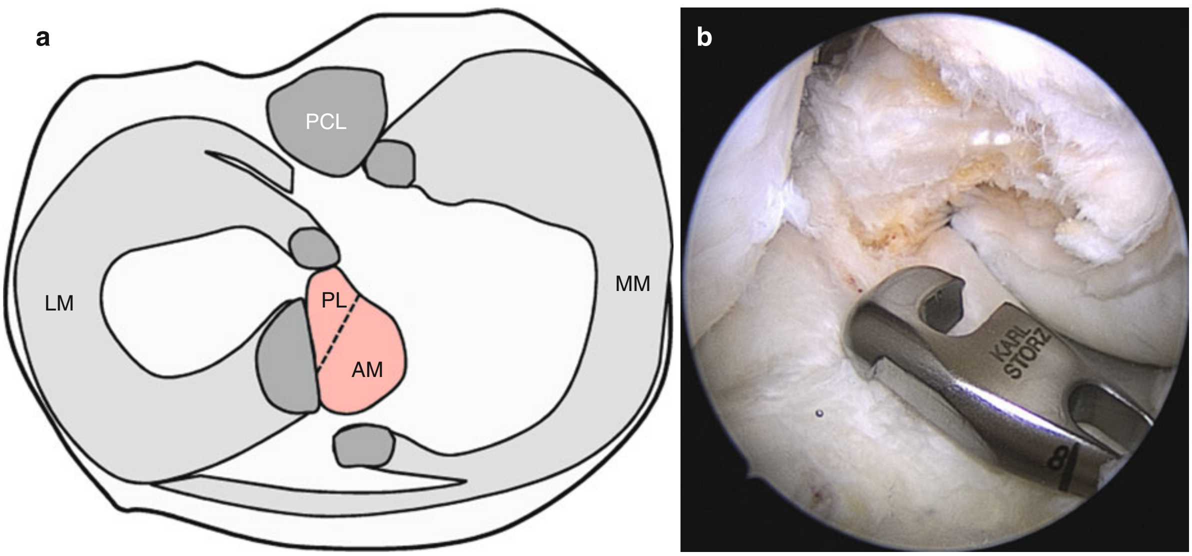

Fig. 24.10 (**a**) Schematic drawing of the tibial insertion zone of the ACL. (**b**) Tibial drill guide (Karl Storz, Germany) in place. *PCL* posterior cruciate ligament, *MM* medial meniscus, *LM* lateral meniscus, *PL* postero-lateral bundle of the ACL, *AM* antero-medial bundle of the ACL

footprint [3]. Drilling via the medial portal results in a more anatomical tunnel position [3]. At the tibia, a solid landmark for tunnel placement is the anterior horn of lateral meniscus (Fig. 24.10).

The ACL can be reconstructed either by single- or double-bundle techniques. Biomechanical and clinical studies (KT 1000, Pivot) revealed the double-bundle technique restores higher stability than single-bundle reconstruction [15, 18, 32]. Clinical scores, however, could not reveal any difference yet. Long-term data of double-bundle reconstruction is not available yet. With regard to the higher risk of double-bundle reconstruction, the single-bundle technique is still the standard method.

24.2.9 Revision After ACL Surgery

A successful revision surgery after ACL surgery requires an appropriate preoperative diagnostic procedure. This is to identify the cause of failure (Fig. 24.11). The most frequent cause for failure is incorrect tunnel placement. Depending on the tunnel position and a possible tunnel widening, the surgeon must decide whether a one- or a two-step operative strategy in necessary. The plain radiographs of the knee can give a first hint on the tunnel position. The CT scan and 3-Dreconstructions enable the surgeon to evaluate the tunnel position more precisely (Fig. 24.5). We distinguish between anatomical

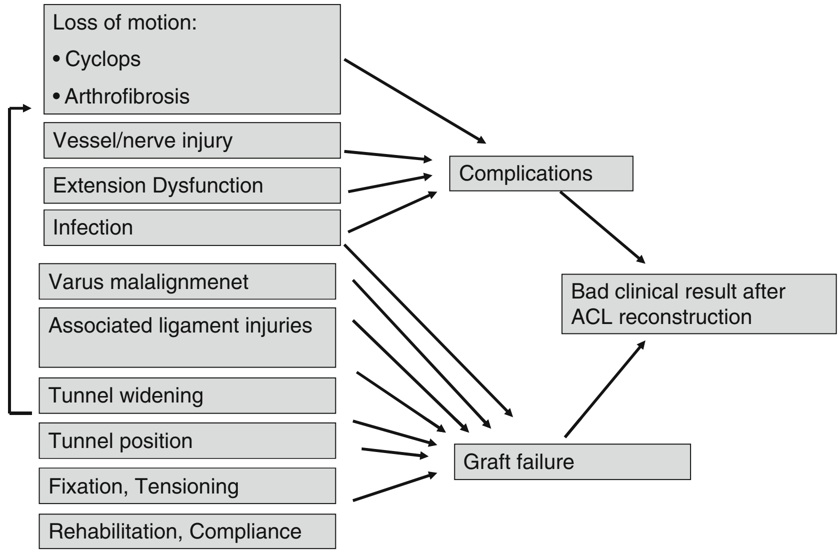

Fig. 24.11 Causes of failure after ACL reconstruction

tunnel positions, partial anatomical tunnel positions, and extraanatomical tunnel positions. A frequent malposition of the graft is the so-called "high noon position." The high noon graft inserts at a precipitous angle into the roof of the Fossa intercondylaris. At the tibia anterior and posterior, malpositions are possible.

Partial anatomical tunnel placement as the reason for malfunction and instability is difficult to treat. In these cases, the bone tunnels have to be revised in a two-step procedure. Therefore, the tunnels are filled up with autologous cancellous bone.

The CT scan secondary gives information about tunnel width. In case of massive tunnel widening, the tunnels should be filled with cancellous bone. ACL reconstruction can be performed after 3–6 months, after stable healing of the cancellous bone with the tunnels.

Stress radiographs also play a role in preoperative planning to exclude neglected posterior instability. Varus malalignment also has to be excluded. In case of varus malalignment and medial osteoarthritis, a high tibial osteotomy (HTO) could be necessary to unload the medial compartment. If HTO is necessary, a two-step procedure is recommended. First, the mechanical axis should be corrected. If subjective instability remains, ACL reconstruction can be performed in a second step. Combination of both procedures (one-step: HTO and ACL reconstruction) can be performed, especially in young patients showing medial pain and instability.

24.2.10 Rehabilitation After ACL Reconstruction

Rehabilitation after ACL reconstruction is complex and time consuming. There are postoperative changes in the graft that reduce mechanical strength (necrosis, revascularization, ligament remodeling). The remodeling takes time up to 1 year after surgery.

The aim of the early phase of the rehabilitation period (4–14 days after surgery) is to reduce pain and inflammation (cooling, isometric quadriceps training, partial weight bearing). NSAIDs should be avoided because of a negative influence on ligament healing in bone.

After 2 weeks, weight bearing can be increased moderately. During this time, the range of motion can be increased. In case of persisting lack of extension, a re-arthroscopy should be performed. A cyclops lesion could be responsible for persisting lack of extension. The aim of the rehabilitation program is the improvement of force and range of motion (ROM). Improvement of proprioception and neuromuscular training should also be performed. Higher-risk sports should not be performed until 6 months after surgery.

24.3 Posterior Cruciate Ligament (PCL)

PCL injuries are rare injuries, and especially injuries due to low-energy trauma (sports trauma) are often missed. In polytrauma patients these injuries may be missed because other injuries are more in the foreground.

24.3.1 Anatomy and Biomechanics

The PCL consists of two functional bundles. The anterolateral bundle (AL) is a strong bundle and it is tensioned in 90° of flexion. The posteromedial (PM) bundle is thinner. The PM is tensioned in extension and in maximal flexion. The PCL is accompanied by the anterior and posterior meniscofemoral ligament.

The PCL is the strongest stabilizer against posterior tibial translation, especially during flexion. Close to extension, other structures such as the posteromedial and posterolateral corner stabilize against posterior tibial translation. The posterolateral structures consist of the lateral collateral ligament (LCL) and the popliteus complex. The LCL stabilizes against varus stress and the popliteus complex stabilizes in external rotation of the tibia against the femur. The posteromedial structures consist of the superficial and deep medial collateral ligament (MCL), the posterior-oblique ligament, and the posteromedial capsule. The posteromedial capsule and the posterior-oblique ligament mainly stabilize against posterior tibial translation.

24.3.2 Epidemiology and Injury Mechanism

Injuries of the PCL are mostly high-energy injuries (dashboard injury, motorbike accident). In high-energy injuries, there is high incidence of concomitant injuries. An epidemiologic study revealed that 40 % of PCL injuries result from sport accidents [30]. A fall on the tibial tuberosity is a common mechanism.

24.3.3 Concomitant Injuries

Isolated PCL ruptures are rare. Due to posterior knee subluxation, damage of the vessels and nerves in the Fossa poplitea or of the peroneus nerve can occur. The extensor mechanism may be affected, and a combination of femur fracture and PCL rupture is common.

There is high incidence of concomitant ligament injuries. Injuries of posterolateral and posteromedial structures are especially common. The incidence of concomitant posterolateral ligament injuries is 60–75 %. The incidence of concomitant posteromedial injury is 50 % [6].

24.3.4 Natural History After PCL Rupture

Isolated PCL ruptures have a high healing potential. In these cases, a conservative approach can be successful. Combined injuries of the PCL and the posteromedial or posterolateral structures frequently lead to chronic instability. An arthroscopic study revealed a high incidence of damage of the cartilage due to chronic instabilities after PCL rupture [31]. Most cartilage damage was seen in the medial compartment followed by damage in the femoropatellar and the lateral compartment.

Posterior subluxation of the tibia increases the joint pressure in the femoropatellar joint and may cause degenerative cartilage damage. There might be two reasons for high incidence of cartilage damage in the medial compartment: (1) Shearing forces in the femorotibial joint caused by increased tibial translation or (2) functional varus due to posterolateral instability.

24.3.5 Diagnostics

Inspection and history may give a first hint on a PCL lesion. Every contusion close to the Tuberositas tibiae should be suspicious. Hematoma in the Fossa poplitea or close to the posterolateral corner are also signs for injury of the PCL.

The typical test for PCL function is the posterior drawer test in 90° of flexion. In PCL-deficient knees, the tibia often shows a spontaneous posterior translation in 90° of flexion (Sag sign). The problem with the manual drawer test is the difficulty of quantifying the measurement.

Rotational drawer tests in external and internal rotation gives hints to posterolateral and posteromedial instability (Fig. 24.12). The diagnosis of these instabilities is challenging. These instabilities can be divided into a varus, a valgus, and a rotational component (Fig. 24.13). Combinations are frequent. To evaluate the rotation component (Popliteus complex), the Dial test can be used. The knee is rotated in 30° and in 90° of flexion. The findings are compared to the contralateral side. To check the stability in the frontal

Fig. 24.12 Posterior drawer in (**a**) neutral position, (**b**) in external rotation, (**c**) in internal rotation

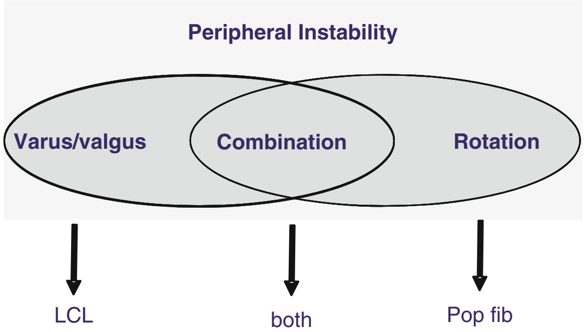

Fig. 24.13 Classification of peripheral instabilities

plane (medial and lateral collateral ligament), valgus and varus stress are applied on the knee in 0° and in 30° of flexion. Opening of the joint space in extension is a hint of a high-grade instability of one of the collateral ligaments.

To quantify posterior tibial translation, stress X-rays should be performed with a defined load applied on the tibial tuberosity (Fig. 24.14). A posterior translation of more than 5 mm is suspicious for a posterior instability. In case of more than 12 mm, concomitant injuries of posterolateral or posteromedial structures are possible. With an anterior-orientated force on, stress X-rays may also help to exclude a fixed posterior translation of the tibia (Fig. 24.15). If the posterior translation cannot be reduced when anterior orientated force is applied, the posterior fixated translation is detected.

In case of chronic posterior instabilities, the MRI is of a subsidiary relevance because it cannot give any functional information. In cases of acute trauma the MRI can provide clues about the trauma and concomitant injuries, especially of injuries of the posteromedial and the posterolateral structures.

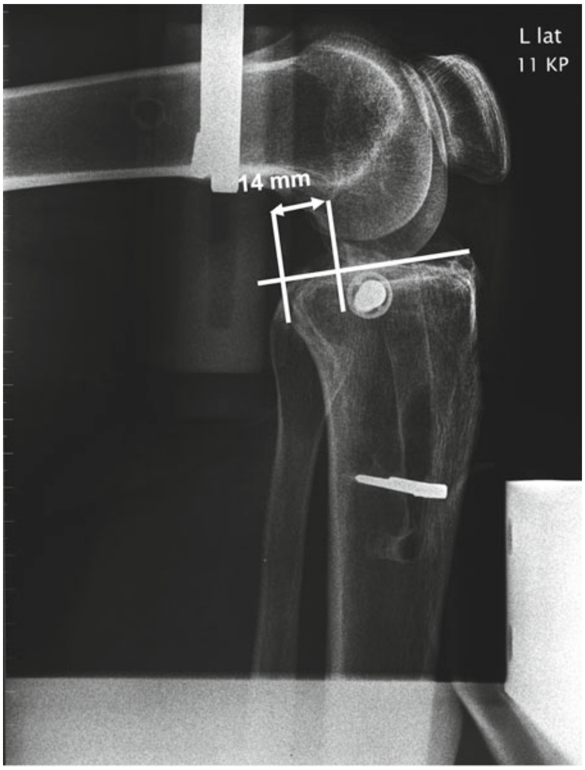

Fig. 24.14 Posterior stress X-ray

If clinical examination reveals a possible varus alignment, whole leg weight-bearing X-rays should be performed. The axis is relevant for therapy of the posterolateral instability.

The PCL is hard to visualize arthroscopically. From the anterior approach, only the proximal third can be visualized. The PCL is surrounded by synovia. A direct evaluation of the ligament can only be performed after partial resection of synovia. In most patients with chronic instability, however, a continuous

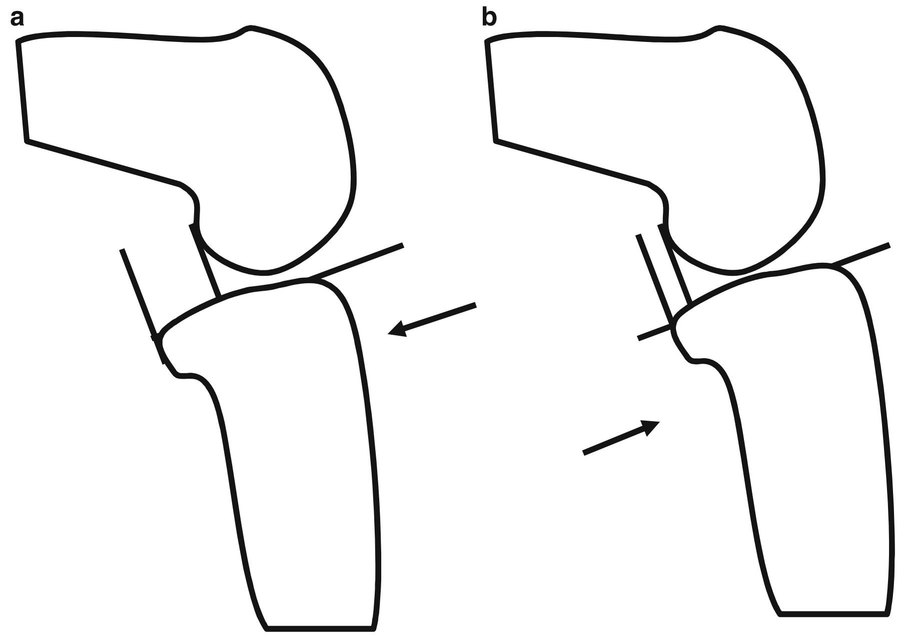

Fig. 24.15 (**a**, **b**) Schematic drawing of fixed posterior tibial subluxation.

but elongated ligament is present. That is why the arthroscopical findings should be evaluated in combination with the clinical and radiological findings. A seeming elongation of the ACL due to posterior subluxation of the tibia can be difficult (floppy ACL sign).

Arthroscopy can be helpful in case of concomitant posterolateral or medial instability. If the joint space opens in the “figure 4” position, a concomitant injury of the posterolateral structures exists. The same is true for the medial side.

24.3.5.1 Fixed Posterior Subluxlation

If the tibia cannot be reduced to the neutral position when applying an anterior directed force, the posterior subluxation is fixed (Fig. 24.15). This state has to be proven by stress X-rays.

Different causes can lead to this condition. One is a reconstruction of a floppy ACL. Fixed posterior tibial translations were also reported after PCL-reconstructions with grafts of the extensor apparatus (agonist to the PCL) or after a long period between accident and treatment.

In case of a fixated posterior subluxation of the tibia without an ACL reconstruction, a PTS brace (PTS Brace, Medi, Bayreuth) is applied at night. This therapy takes time, up to months. The aim is to create an instability again by releasing the fixated posterior instability. An arthroscopical arthrolysis is infrequently necessary.

24.3.6 Therapy

24.3.6.1 Acute Injuries

In cases of acute injuries, therapy is relevant if there is an isolated PCL injury or if a combination of injuries exists. Isolated PCL injuries have good healing potential and can be treated without operation. The patient is treated with a brace in extension position for 6 weeks (PTS Brace, Medi, Bayreuth). The brace has a supporting pad for the gastrocnemius. This helps to avoid a posterior subluxation due to gravity. Physiotherapy can be performed only in the prone position (2 weeks 20°, 2 weeks 40°, 2 weeks 60°). After that time, patients must wear a moving brace for 6 weeks. During the night, the PTS brace should still be used.

In case of concomitant injury of the posteromedial or posterolateral structures, an early suture repair of these structures should be performed. Depending on other concomitant injuries, the need of an early reconstruction of the PCL has to be balanced individually.

24.3.6.2 Chronic Instabilities

In case of symptomatic chronic instability, arthroscopic reconstruction of the PCL with an autologous tendon graft is indicated (Fig. 24.16). Graft options are the hamstring tendons, the patellar tendon, or the quadriceps tendon. The hamstring tendons should be preferred, because graft harvesting does not impair the extensor apparatus.

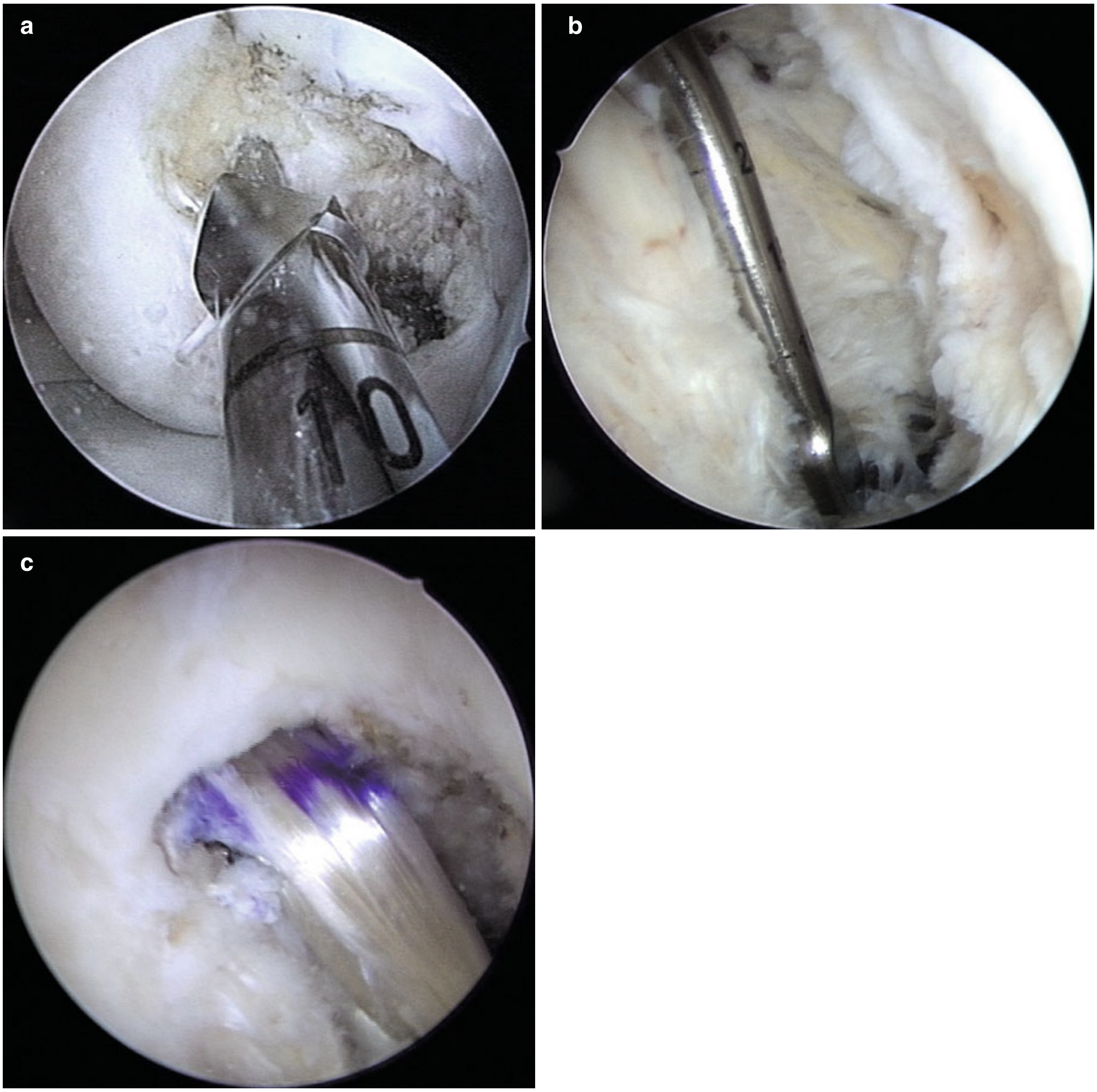

Fig. 24.16 Arthroscopic PCL reconstruction. (**a**) Drilling the femoral tunnel via a deep anterolateral portal. (**b**) Tibial PCL aimer in place (Karl Storz, Germany). (**c**) PCL graft

Indication for PCL reconstruction is seen in cases with more than 10 mm of posterior tibial translation. If posterior tibial translation is less 10 mm a brace test is indicated. In case of posterolateral instability, a simultaneous posterolateral reconstruction with a contralateral semitendinosus graft should be performed (Fig. 24.17). At the medial side, there are several options: (1) healing stimulation, (2) plication, and (3) posteromedial reconstruction techniques with allografts. In case of a posterolateral instability combined with a varus malalignment, a high tibial medial open wedge osteotomy should be performed. Without correction of the axis, failure of the posterolateral graft is probable. Indication for single correction of the posterior slope is rare and mostly indicated in revision cases.

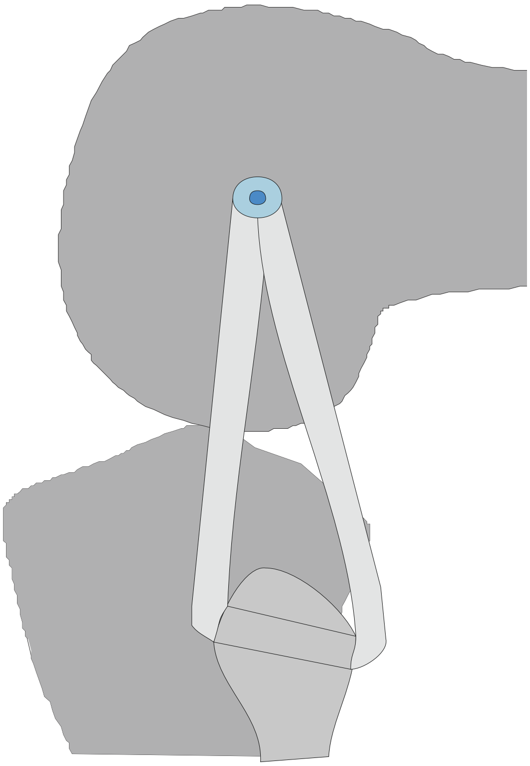

Fig. 24.17 Schematic drawing of a fibulotibial sling (Larson technique) for posterolateral reconstruction

24.3.7 Rehabilitation

After PCL reconstruction, a nonaggressive rehabilitation program should be performed. A PTS brace in extension is applied for 6 weeks. Exercise should be performed only in the prone position for 6 weeks. After 6 weeks, a flexible brace is applied to the knee. The PTS brace is used for 6 more weeks, only at night.

24.4 Collateral Ligament Ruptures

24.4.1 Anatomy

The medial collateral ligament complex consists of the superficial medial collateral ligament (sMCL), the deep medial collateral ligament (dMCL), the posterior oblique ligament (POL), and the posterior capsule.

The lateral collateral ligament spans from the lateral epicondyle to the fibula head. An active component of the lateral complex is the popliteus tendon. The popliteus tendon is connected to the fibula head by the popliteofibular ligament.

24.4.2 Trauma

Collateral ligament injuries result from valgus or varus trauma. Complete collateral ruptures are rarely isolated injuries. If a complete rupture is diagnosed, the examiner should look for further associated ligament injuries (ACL and PCL).

Sprains and partial ruptures are more frequent than complete ruptures. These injuries results from sports trauma and can also be isolated.

24.4.3 Diagnosis

Collateral ligament injuries can be diagnosed with the varus or valgus stress test in 0° and 20° of flexion. A complete rupture can be diagnosed when the joint space opens in extension without a firm endpoint. To exclude rotational instability, a dial test and rotational drawer has to be performed. The examination should always include the cruciate ligaments to exclude associated injuries.

In the acute setting, MRI can be helpful to localize the lesion (femoral or fibular avulsion injuries, intraligamentous lesions, distal tibial lesions of the medial collateral ligament).

24.4.4 Treatment

24.4.4.1 Medial Collateral Ligament

The medial collateral ligament has a good healing potential [19]. Therefore, sprains and partial ruptures should be treated conservatively. Isolated complete ruptures can also be treated conservatively. In these cases, a movable brace is applied for 6–8 weeks. In combined ligamentous injuries, repair should be considered. Especially in distal lesions, when the distal stump is retracted and the pes anserinus could prevent healing to the tibia, repair can be indicated.

In case of chronic instabilities there are several options: (1) healing stimulation, (2) plication, and (3) posteromedial reconstruction techniques with allografts.

24.4.4.2 Lateral Collateral Ligament

At the lateral side, conservative treatment has a good prognosis in grade I and II injures (sprains and partial ruptures). In case of a complete rupture, repair is indicated. Distal avulsion injuries of the LCL at the fibula have a good prognosis. In these cases, refixation with a suture anchor should be performed. Third-degree intraligamentous injuries have a high risk for failure. In these cases, an additional augmentation with an auto- or an allograft should be is recommended. Common techniques are a fibulofemoral sling (Larson technique), a tibiofemoral bypass, or a biceps tenodesis.

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Tibial Plateau Fractures

25

Philipp Kobbe and Hans-Christoph Pape

25.1 Introduction

Fractures of the tibial plateau interfere with knee function and stability. The degree of impairment depends on the fracture pattern as well as associated ligamentous or meniscal injuries. Today, diagnostic tools allow precise identification of injured structures and assist in decision making as to whether operative management is necessary.

25.2 Anatomy and Biomechanics

The normal anatomic alignment of the knee is in 7° of valgus with a load distribution of 60 % on the medial and 40 % on the lateral plateau. This load distribution results in a larger, concave, and stronger medial plateau as compared to a smaller, convex, and less strong lateral plateau. Because of the convexity of the lateral plateau, the lateral joint surface sits slightly higher than the medial one, forming an angle of 3° of varus with respect of the tibial shaft. This may be useful in differentiating the plateaus on X-rays.

Both plateaus demonstrate a posterior slope of 10–15°. A fibrocartilaginous meniscus covers both plateaus and improves femorotibial joint congruency. The coronary ligaments serve to attach the menisci to the plateaus and the intermeniscal ligament serves to connect the menisci anteriorly. Often, this ligament is incised and elevated to afford direct visualization of the articular surfaces. The tibial spines are located in the middle of the plateaus and serve as attachment points for the anterior and posterior cruciate ligaments as well as the menisci. The stability of the knee joint depends on the integrity of the cruciate and collateral ligaments, the capsule, and the menisci.

25.3 Pathogenesis

The injury mechanism of low-energy tibial plateau fractures is an axial impact of the femoral condyle into the tibial plateau. Because of the valgus axis of the leg as well as the less strong lateral plateau, this usually results in lateral plateau fractures. High-energy tibial plateau fractures are associated with a more complex fracture pattern (bicondylar fractures) and frequent concomitant severe soft-tissue injuries. These fractures are classically caused by road traffic accidents or sports injuries. Generally, split or wedge fractures with or without ligamentous injuries occur in younger patients with dense bone, whereas depression fractures are more predominant in older patients with osteoporotic bone.

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25.4 Diagnostics

25.4.1 Clinical Examination

The soft tissue injury should be assessed. The marginal soft tissue envelope of the proximal tibia predisposes to open fractures and development of soft tissue necrosis. Compartment syndrome should be ruled out. If there is doubt about the indication for surgery, knee stability should be tested. Varus/valgus stress testing of the knee in near-full extension with an articular widening of the femoral-tibial articulation greater than 10° indicates knee instability. Neurovascular status should also be checked.

25.4.2 Imaging

Radiographic evaluation includes the plain anteroposterior and lateral radiographs. Computed tomography (CT) is the standard tool in analyzing tibial plateau fractures, because the degree of articular depression as well as the number and localization of fragments is often underestimated in plain radiographs. Further, CT scans are helpful in preoperative planning. Although the magnetic resonance imaging (MRI) evaluates both osseous and soft tissue injuries, there is currently no clear consensus for the use of MRI in tibial plateau fractures. It may be helpful in identifying associated meniscal and ligamentous injuries.

25.5 Classification

Several classifications categorize tibial plateau fractures; however, the majority of these systems are similar to one another and each one recognizes wedge, compression, and bicondylar types (Table 25.1).

Table 25.1 AO and Schatzker classification for tibial plateau fractures. Note that a Schatzker IV injury (split (type A) or depression (type B) fracture of the medial plateau) is not included in this table

AO	Schatzker	Description
41-A		Extra-articular fractures
41-B		Partial intra-articular fractures
B1	I	Split fracture of the lateral plateau
B2	III	Depression fracture of the lateral plateau
B3	II	Split-depression fracture of the lateral plateau
41-C		Complete articular fractures
C1	V	Simple bicondylar fracture with simple metaphysal fracture
C2		Simple bicondylar fracture with comminuted metaphysal fracture
C3	VI	Comminuted articular and metaphysal fracture

25.6 Associated Injuries

Anterior cruciate ligament injuries are found in up to 23 % of patients, meniscal injuries in up to 50 % of patients, and collateral ligament injuries in up to 43 % of patients.

25.7 Management

The outcome following tibial plateau fractures is closely associated with the degree of articular depression and knee stability. Knee instability may result from the fracture itself and from accompanying injuries such as meniscal injuries or rupture of cruciate or collateral ligaments. For nondisplaced fractures, nonoperative management is justified. Displaced fractures require anatomic restoration of the intraarticular fragments.

25.7.1 Nonoperative Management

Nonoperative management is indicated for stable knee joints with articular depression <1 cm. The patient may undertake partial weight bearing in a hinged fracture brace for 8–12 weeks. The mainstay of nonoperative care is intensive physical therapy with early motion and isometric quadriceps exercises to avoid muscle atrophy and joint stiffness.

25.7.2 Operative Management

25.7.2.1 General Aspects of Surgical Management

Indications for emergency operative management are open tibial plateau fractures and tibial plateau fractures with associated neurovascular injuries or compartment syndrome. Displaced tibial plateau fractures (>1 cm articular depression) or tibial plateau fractures resulting in an unstable knee joint (more than 10° varus/valgus instability) are indications for operative management. The mainstay of operative care is open reduction and internal fixation (ORIF) with anatomic reduction, which is an important aspect for cartilage regeneration. Minimally invasive approaches (MIPO technique) are the standard of care for surgical management of tibial plateau fractures because the marginal soft tissue envelope predisposes for tissue necrosis and infection.

Delayed internal fixation with primary external stabilization may be necessary in high-energy injuries with severe soft tissue destruction. Nonlocking plates are suitable for simple fracture patterns with minimal comminution, whereas locking plates are indicated for high-energy fractures, those with severe comminution, and in osteoporotic bone. Adequate reduction should be achieved by the use fluoroscopy. Arthroscopic-assisted reduction and internal fixation may be helpful in pure depression fractures; however, extravasation of irrigation fluid, especially in extracapsular fractures, carries the risk of a compartment syndrome and must be used with extreme caution.

25.7.2.2 Lateral Plateau Fractures (AO-41-B1/B2/B3)

Fixation of pure split fractures of the lateral plateau (AO-41-B1//Schatzker I) may be achieved with two or three percutaneously inserted 6.5- or 7.0-mm partially threaded cancellous bone screws with washers. In cases of fracture fragmentation or in osteopenic patients, a lateral buttress plate may be used in an anti-glide position (Fig. 25.1). In depression fractures of the lateral plateau (AO-41-B2//Schatzker III), the depression is elevated through a cortical window. Often, bone graft or bone substitute is needed. Stabilization is achieved with two or three 6.5- or 7.0-mm subchondral cancellous bone screws in "rafting" position (Fig. 25.2). In split-depression fractures of the lateral plateau (AO-41-B3//Schatzker II), the depression is elevated through the split component and the application of bone graft or bone substitute may be needed. Stabilization is achieved with lateral plate osteosynthesis with the proximal screws in "rafting" position (Fig. 25.3).

25.7.2.3 Bicondylar Plateau Fractures (AO-41-C1/C2/C3)

These are usually high-energy tibial plateau fractures with mangled soft tissues that frequently do not allow immediate ORIF and may require primary external stabilization until the soft tissue envelop has recovered. Simple bicondylar fractures with simple metaphysal fractures (AO-41-C1//Schatzker V) may be managed with a lateral locking plate, which usually provides as much as stability as dual plating, however, is associated with less soft tissue dissection. Simple or comminuted bicondylar fractures with comminuted metaphysal fractures (AO-41-C2 and AO-41-C3//Schatzker VI) are insufficiently stabilized by a laterally based plate alone and usually require additional fixation (double-plating) to prevent varus malunion, despite the use of locking techniques.

25.7.3 Postoperative Care

Rehabilitation depends on patient age, bone quality, type of osteosynthesis, and concomitant injuries. Early mobilization is key to the successful treatment of proximal tibia fractures to avoid later knee stiffness, muscle wasting, and achieve full range of motion:

- 90° flexion should be achieved by 7–10 days.
- Toe-touch weight bearing is recommended for 4–8 weeks with progression thereafter according to radiographic findings.

25.8 Complications and Prognosis

Nonunion rate is up to 8 %. The incidence of wound infections correlates with the fracture type, the soft-tissue injury, and the amount of hardware implanted and ranges from 0 to 32 % for fractures managed with buttress technique. Deep vein thrombosis rates are between 5 and 10 %. Pulmonary embolus occurs in 1–2 % of patients. Hardware failure with loss of fixation with axial malalignment and valgus deformity occurs in less than 12 %. Some patients develop post-traumatic arthritis.

The outcome depends mostly on four factors:

- Joint congruity
- Meniscal integrity
- Knee stability
- Correct axis

A favorable outcome has been reported for surgically treated low-energy tibial plateau fractures. About 90 % of patients have good and excellent results, but the outcome may be compromised if one of the four mentioned factors is not fulfilled. It has to be noticed that, even in the face of poor radiographic results, satisfactory functional outcome may be achieved if the menisci and their load-bearing ability are preserved.

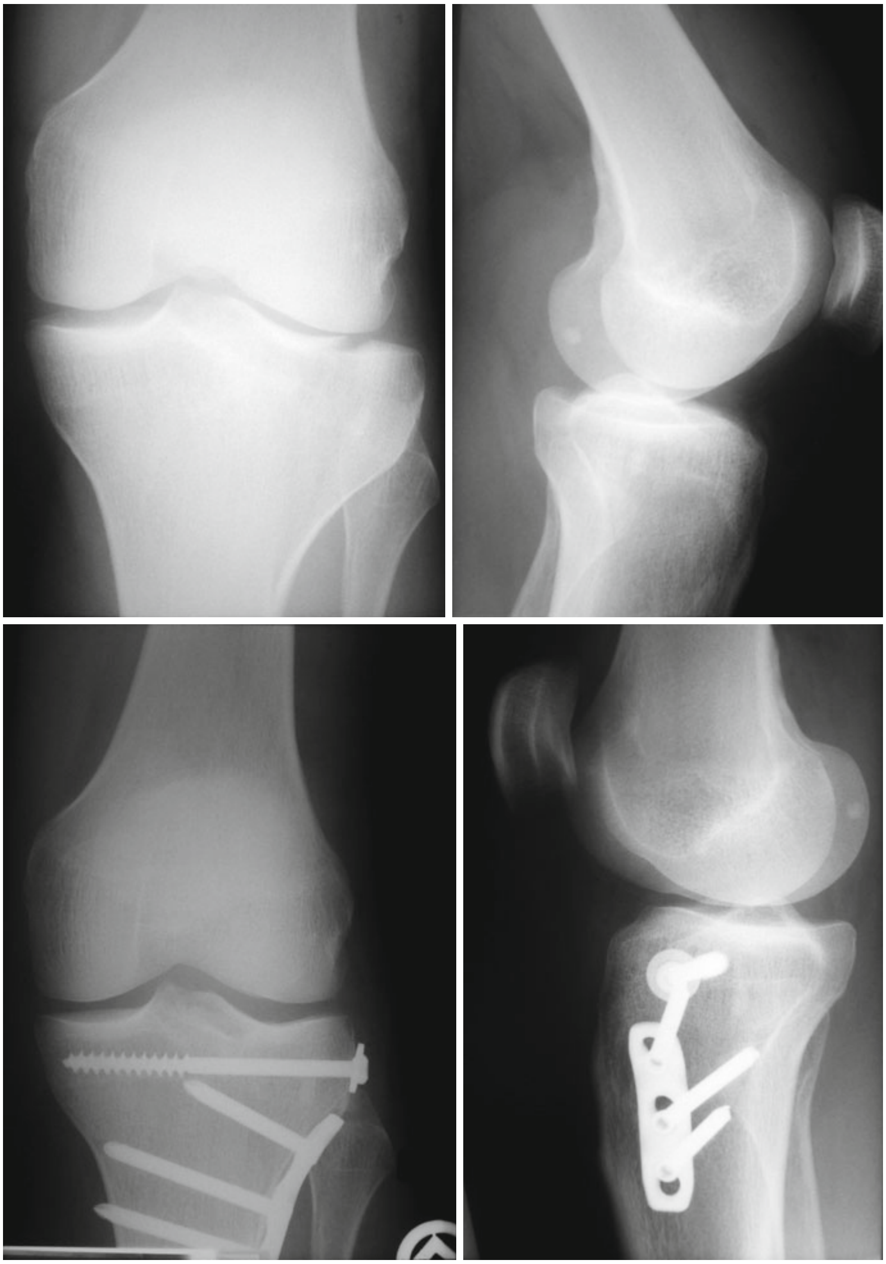

Fig. 25.1 AO-41-B1// Schatzker I fracture managed with a threaded 6.5-mm cancellous bone screw with washer and a lateral buttress plate in antiglide position

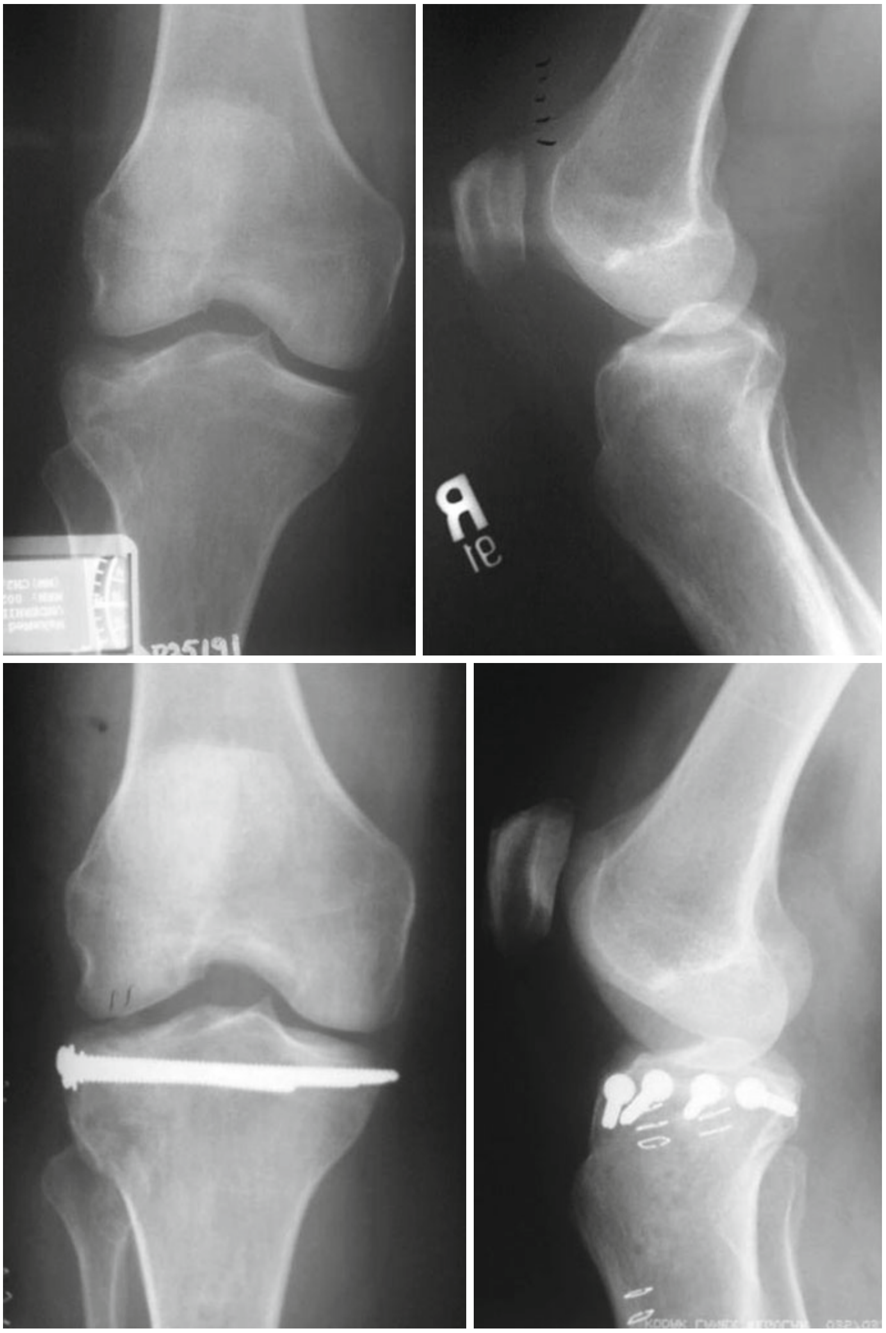

Fig. 25.2 AO-41-B2// Schatzker III fracture managed with four 6.5-mm subchondral cancellous bone screws in "rafting" position

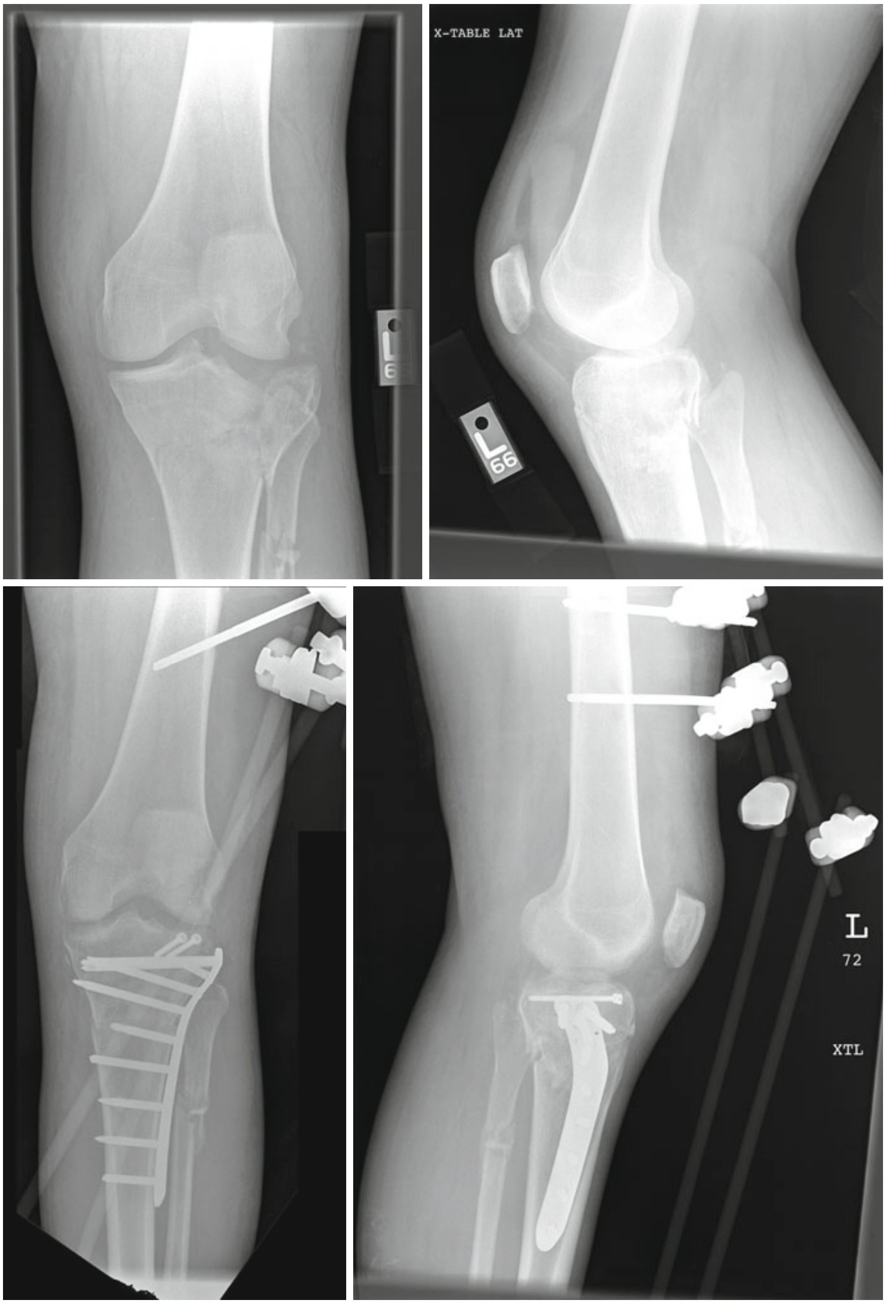

Fig. 25.3 AO-41-B3// Schatzker II fracture managed with lateral plate osteosynthesis with the proximal screws in "rafting" position

Conclusion

Function and stability of the knee joint may be impaired by fractures of the tibial plateau. Computer tomography allows for exact analysis of the fracture pattern and guides further operative fixation. Nonsurgical management is an option in nondisplaced fractures, whereas surgical management is the standard of care in displaced fractures and the implementation of minimal invasive techniques has improved clinical outcome. Overall, outcome following tibial plateau fractures depends on restoration of joint congruity, knee stability, meniscal integrity, and axial alignment. Usually, low-energy tibial plateau fractures are associated with good to excellent results in most cases. However, the prognosis for high-energy fracture patterns is less predictable.

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Tibial Shaft Fractures

26

Philipp Lichte and Hans-Christoph Pape

26.1 Introduction

Tibial shaft fractures are the most common long bone fractures. With technical improvements in nails, today almost all fractures can be treated with locked intramedullary nails.

26.2 Anatomy and Biomechanics

The tibial bone can resist flexural forces up to 1.5 t and is the most rigid bone in the human body. The tibia and fibula are parallel in the midshaft region: at the proximal junction is the tibiofibular joint; at the distal is the ankle joint with tibiofibular syndesmosis. The interosseus membrane is located between the tibia and fibula. It separates muscular compartments into anterior and posterior groups and stabilizes the osseus structures.

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Overall the lower leg is divided into four compartments by fascial layers:

- *Anterior compartment*: Tibialis anterior muscle, long extensor hallucis muscle, long extensor digitorum muscle, anterior tibial artery, deep peroneal nerve
- *Lateral compartment*: long and short peroneal muscles, superficial peroneal nerve
- *Superficial dorsal compartment*: gastrocnemius muscle, plantaris muscle, soleus muscle
- *Deep dorsal compartment*: long flexor digitorum muscle, long flexor hallucis muscle, tibialis posterior muscle, posterior tibial artery, tibial nerve

The anteromedial edge of the tibia is covered by subcutaneous tissue and is at special risk for open fractures.

26.3 Pathogenesis

Tibial shaft fractures are usually caused by high-energy trauma. Low-energy fractures may be caused by torsion or indirect trauma, especially in the elderly. In these cases, the tibia and fibula fractures occur at different levels and have little soft tissue injury. High-energy tibial shaft fractures are caused by direct trauma and are typical for motorcyclists or pedestrians ("bumpers fracture"). Typical characteristics are

- Bony comminution
- Oblique fracture types
- Fibula fracture at same level
- Open fractures with severe tissue injury

Stress fractures of the tibial shaft account for more than 50 % of all stress fractures. They are caused by overuse injury in dancers, runners, and jumping athletes.

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26.4 Diagnostics

The diagnosis is based on clinical and radiological findings.

Clinical Findings

- Localized pain
- Deformity
- Instability

Documentation of soft tissue injury and neurovascular state is mandatory. In stress fractures, the main symptom is localized pain area over the fracture following exercise.

Radiological Examination

- Lateral and anteroposterior (a.p.) X-ray of the lower leg, including the adjacent joints
- Stress fractures may sometimes only be detectable by MRI or triple-phase bone scan ("focal hot spot")

26.5 Classification

Tibial shaft fractures are classified according to the association for the study of internal fixation (AO-ASIF) classification:

- A: simple fractures
  - A1: spiral
  - A2: oblique (>30°)
  - A3: transverse (<30°)
- B: wedge fractures
  - B1: spiral wedge
  - B2: bending wedge
  - B3: fragmented wedge
- C: complex fractures
  - C1: spiral
  - C2: segmented
  - C3: irregular

The soft tissue injury can be classified according to "Tscherne/Oestern" or "Gustillo/Andersen."

26.6 Associated Injuries

Isolated tibial shaft fractures are rare. Most tibial shaft fractures are combined with fractures of the fibula. In severe displaced fractures, associated injuries of the anterior tibial artery and the peripheral nerves are frequent. Most high-energy shaft fractures are associated with multiple other injuries.

26.7 Management

26.7.1 Nonoperative Management

In general, the indication for nonoperative management is rare because operative fracture stabilization is safe and effective. In cases of stable fractures without displacement (42-A1–42-A3), nonoperative treatment can be performed, such as immobilization in a long-leg cast or Sarmiento brace for 10–12 weeks. Early functional treatment can begin at the 2-week time point. Traction should only be utilized if closed reduction of closed displaced fractures is necessary until definitive operative care. Stress fractures should be treated by cast immobilization until completion of fracture healing.

26.7.2 Operative Management

Selection of the operative method depends on the localization of the fracture, soft tissue injury, the fracture morphology, and associated injuries. In cases of severe bony and soft tissue destruction, salvage of the extremity may not be useful. The goal is to maintain a functional limb; if this is impossible, initial guillotine amputation should be considered. In isolated fractures, the MES (mangled-extremity severity) score may be helpful for decision making. In multiply injured patients with life-threatening injuries, the indication for amputation should follow the principle "life before limb."

Three different methods of fracture fixation are available:

- Intramedullary (IM) IM nailing
- Plate osteosynthesis
- External fixation

26.7.2.1 IM Nailing

With technical improvements in interlocked nails, the indications for intramedullary fixation have become more frequent. Modern nails have very distal screw holes. Intramedullary nailing is widely accepted as the treatment of choice in most tibial shaft fractures. Figure 26.1 shows a typical indication for IM nailing.

Intramedullary nailing is indicated in cases of:

- Open fractures
- Severe soft tissue injury
- Segmental fractures

Fig. 26.1 A closed fracture of the middle third of the tibial shaft as a typical indication for IM nailing with the possibility of early weight bearing

- Polytraumatized patients and additional ipsilateral fractures
- Morbid obesity
- Unstable high-energy fracture

Whether reamed or unreamed nailing is preferable is a controversial issue. Reaming allows for larger nail diameter and may offer increased initial stability in comminuted fractures.

26.7.2.2 Plate Osteosynthesis

Plate osteosynthesis should be considered for:

- Tibial shaft fractures adjacent to the metaphysic (Fig. 26.2),
- Combined diaphyseal and metaphyseal fractures
- Complex diaphyseal fractures of the proximal third

Plate osteosynthesis requires good soft tissue conditions to minimize the risk of infection and wound healing issues. The choice of plate should be tapered according to the fracture type.

- *Transverse fractures*: low contact-dynamic compression plate (LC-DCP)
- *Wedge fractures*: interfragmentary compression screws and neutralization plate, LC-DCP
- *Spiral fractures*: interfragmentary compression screws and neutralization plate, LC-DCP
- *Oblique fractures*: interfragmentary traction screws and neutralization plate, LC-DCP
- *Comminuted fractures*: bridge plates

Locking plates are especially advantageous in osteopenia. They can also be used for bridging osteosynthesis of fractures with comminuted bone fragments and bone loss. In many cases, a minimally invasive technique may be selected to minimize soft tissue trauma. After closed reduction the plate can be slid forward along the bone through a small incision. In cases of bone loss, primary bone grafting is not recommended because of the soft tissue injury.

Weight-bearing capacity is restricted for 12–16 weeks after plate osteosynthesis. During the first 6 weeks, mobilization with partial weight bearing of 20 kg is usually allowed. Depending on the follow-up X-ray, weight bearing can be increased. Full weight bearing is usually not recommended until 12 weeks after the operation, except in cases of simple transverse fractures.

26.7.2.3 External Fixation

The main indications are fractures with severe tissue damage. The aim of surgery is temporary fixation of the fracture and muscular decompression. In cases of massive bony comminution, an Ilizarov frame may be considered as an alternative and used for definitive treatment.

The following disadvantages have to be considered:

- Increased incidence of malalignment compared with IM nailing
- High rate of pin track complications
- Loosening of Schanz screws

Conversion of external treatment into internal fixation is indicated if:

- Exact and stable reduction is impossible
- If the surgeon expect long lasting healing due to patients or the fractures condition in the first phase of treatment, we recommend an early conversion to internal treatment
- If the construction of the external fixateur has to bridge a joint we also recomend conversion to internal fixation to provide long lasting joint immobilization

26.8 Complications and Prognosis

Early complications are:

- Compartment syndrome
- Soft tissue infection

Late complications are:

- Malunion
- Nonunion
- Hardware failure
- Osteomyelitis

The most common severe early complication is the development of compartment syndrome (incidence, 1–9 %). There are concerns that intramedullary nailing increases the incidence of this complication. Therefore, compartment pressure should be monitored closely perioperatively. Because of the long period of partial weight bearing and constrained range of motion, the risk of deep vein thrombosis is increased. Prophylactic measures should be taken, such as pressure stockings and anticoagulation.

Any given operative technique implies certain risks and side effects:

- *Nonoperative treatment*: ankle and knee stiffness after long-term immobilization
- *IM nailing*: anterior knee pain
- *Plate osteosynthesis*: wound healing deficits, especially in cases of significant soft tissue damage
- *External fixation*: pin track infections are a common problem

Fig. 26.2 A very distal fracture of the lower leg fixed with an interfragmentary compression screw in combination with a locking plate

IM nailing has a success rate of more than 90 %. Overall nonunion is rare. Treatment should include:

- Dynamization of the nail if axially stable
- Exchange reamed IM nail if not axially stable
- In cases of bone loss, bone grafting should be performed to prevent hardware failure.

The functional long-term outcome of isolated tibial shaft fractures treated with intramedullary nailing is comparable to the general population. Work-related disability and persistent pain have been described up to 1 year after intramedullary nailing. In general, below-knee injuries have a worse outcome than above-knee injuries of the lower extremity. Fractures of the tibial shaft account for just a few of these poor clinical outcomes.

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27 Fractures of the Tibial Pilon

Richard Martin Sellei and Hans-Christoph Pape

27.1 Introduction

Fractures of the distal tibia are characterized by the following aspects:

- Frequent intra-articular involvement
- High-energy mechanism with axial load
- Comminuted fracture patterns
- Severe soft-tissue compromise
- Frequent wound healing issues

These fractures are among the most challenging injuries because of the high risk of complications and limited outcome [4, 13, 19]. The result of the treatment is strongly biased by the management and operative care of this type of fracture [26].

The fracture pattern, the severity of the soft-tissue involvement, vascularization, and the surgeon's experience strongly contribute to the prognosis. Historically, the operative treatment of the tibial pilon fracture was implemented by Rüedi and Allgöwer in 1979 [24]. They showed improved results with open reduction and internal fixation and advocated this treatment, suggesting that the nonoperative treatment should be abandoned. The prevalence of complications was high [16, 27] and initiated a staged management leading to improvements in soft-tissue complications [7, 25]. The long-term outcome was determined by the degree of the reduction of the joint surface, degree of initial cartilage damage, poor vascularity, and soft tissue coverage [9, 11, 18]. In addition, different approaches were described to protect the soft-tissue envelope and adapt the surgical approach to the fracture pattern [1, 8, 11]. New developments on the implants, such as angular stability and anatomically contoured, low-profile plates improved the complications rates.

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27.2 Anatomy and Biomechanics

The ankle region carries the full body weight. The distal part of the tibia and the fibula form a frame around the talus and are stabilized by:

- Tibiofibular syndesmosis
- Superficial and deep portion of the deltoid ligament (medial collateral ligament)
- Lateral collateral ligament (anterior and posterior talofibular ligaments and fibulocalcaneal ligament)
- Articular surface
- Capsule

The ligaments of the distal tibiofibular syndesmosis are formed by the interosseous ligament (IOL), anterior inferior tibiofibular ligament (AITFL), and the posterior inferior tibiofibular ligament (PITFL) strengthened by the inferior transverse ligament (ITL). The fibula is locked in a shallow groove in the distal tibia, adjacent to a larger anterior tubercle (*Tubercule de Tillaux-Chaput*) and a smaller posterior tubercle.

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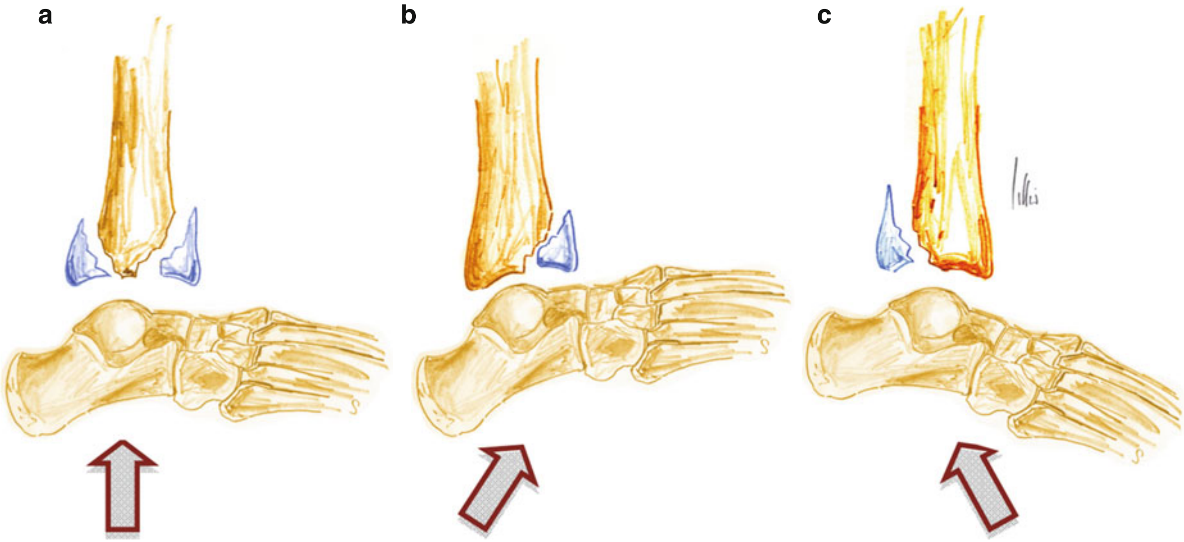

Fig. 27.1 The foot position at the moment of the axial impact. (**a**) Impartial position (**b**) dorsiflexion (**c**) plantarflexion

The distal posterior aspect of the tibia is named posterior malleolus. In tibial pilon fractures, the syndesmosis and the medial collateral ligament are usually not affected by the trauma [3, 23]. The anterior and posterior tibial arteries ensure the blood supply of the distal aspect of the lower leg.

27.3 Pathogenesis

The mechanism of tibial pilon injury is usually caused by high-energy mechanism and axial load. These fractures mostly occur following an injury by a motor vehicle accident or fall from a height. Fractures of the distal tibia account for less than 10 % of all fractures of the lower leg. It is more frequent in men than in women. The incidence is mainly between 35 and 40 years of age [15]. The position of the foot at the time of injury has been emphasized to relate to the fracture pattern [14, 22, 24]. A plantar flexion injury results in a posterior malleolar fragment. Dorsiflexion injury results in an anterior malleolar fragment. A neutral ankle position results in both anterior and posterior malleolar fragments (Fig. 27.1). While malleolar fractures of the ankle are caused mainly by a rotational mechanism, the tibial pilon fracture differs in terms of mechanism, classification, severity, and treatment.

27.4 Classification

Since the 1960s, several classifications have been developed [9, 17, 21–23, 28]. The classifications of the tibial pilon fractures differentiate intra-articular and extra-articular fractures of the distal tibia. They describe the fracture dislocation and implicate by rising intricacy a higher level of soft-tissue damage.

- *Rüedi and Allgöwer classification* (*1968*)
- *Arbeitsgemeinschaft für osteosynthese/orthopaedic trauma association* (*AO/OTA*) *classification* (*1990*)
- *Robinson classification of metaphyseal fractures* (*1995*)
- *Topliss classification of computed tomography* (*CT*) *scans* (*2004*)

Rüedi and Allgöwer described a fracture classification that divides three fractures types, depending on the mechanism: nondisplaced low velocity (Type I), low-energy mildly displaced (Type II), and high-energy comminuted fractures (Type III) [22]. The AO/OTA classification is the most commonly used classification system (Fig. 27.2). Robinson et al. classified the metaphyseal fractures of the distal tibia in order to distinguish these fracture type [21]. They described bending forces (Type I) and torsion mechanisms (Type II).

Most classifications are developed by plane radiographs. Additionally, the CT scan enables subclassifications for detailed grouping. The plane radiographs (anterior-posterior and mortise view) are necessary for

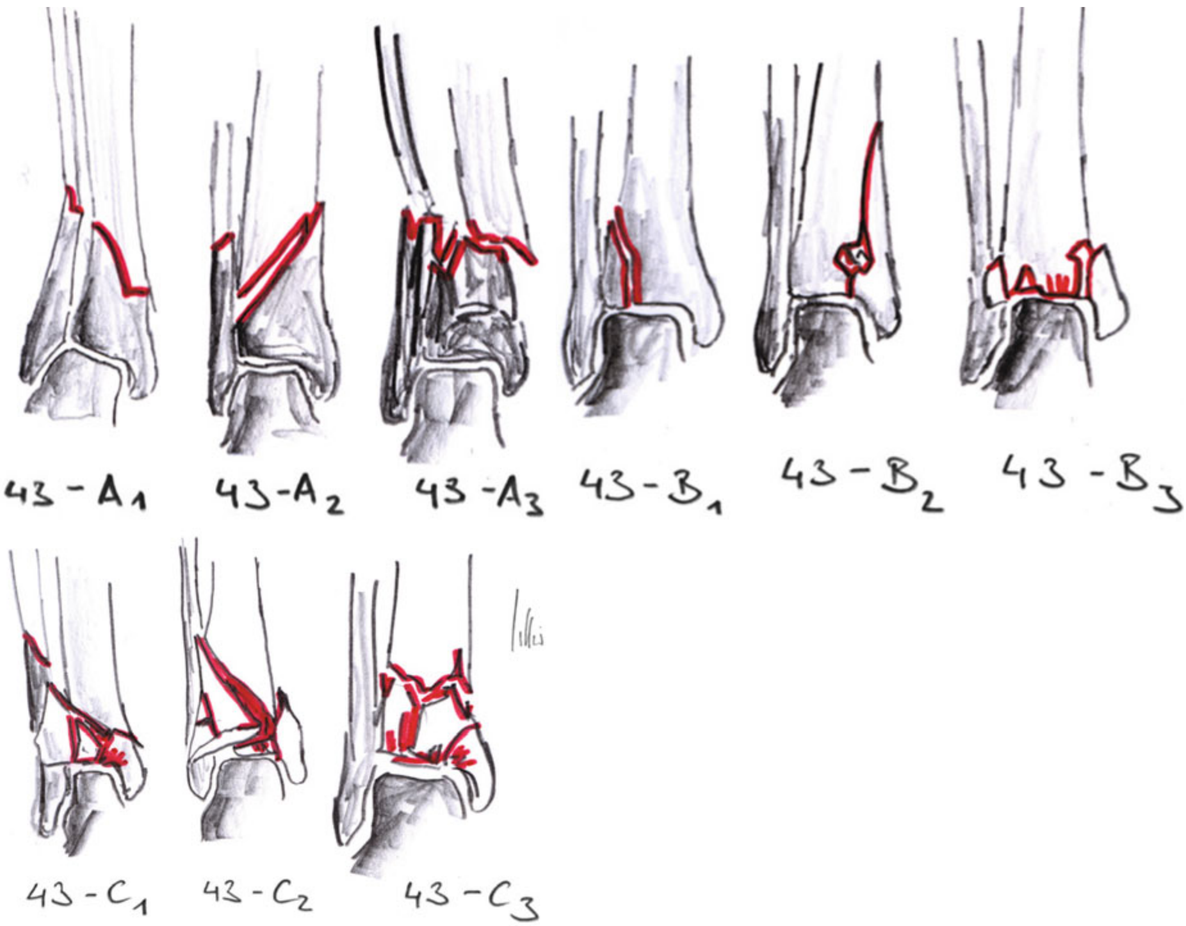

Fig. 27.2 The distal tibia is encoded with the numbers 43 (*4* tibia, *3* distal) and additionally specified with the subclassification of extra-articular (Type A), partial articular (Type B), and complete articular fractures (Type C). There are further subgroups of fractures within these classifications, including the degree of dislocation, comminution, and location of fracture lines

the AO classification. It is also recommended to revise the ankle position after bridging by external fixator. Computed tomography allows for adequate understanding of the fracture morphology and preoperative planning [29]. In CT scans of pilon fractures of the distal tibia, distinct fragments can be recognized [28]. Six different fragments can be distinguished (Fig. 27.3).

- Anterior fragment (A) – (*Tubercule de Tillaux-Chaput*)
- Posterior fragment (P) – (Posterior malleolus or "Volkman")
- Medial fragment (M)
- Antero-lateral fragment (AL)
- Posterolateral fragment (PL)
- Die-punch fragment (DP)

In addition further kind of fracture patterns in coronal and sagittal planes have been distinguished.

27.5 Diagnostics

Distinction of a low- or high-energy mechanism is important to quantify the degree of soft tissue damage.

27.5.1 Clinical Findings

Soft tissue damage involvement ranges from minor swelling up to early necrosis. Adequate assessment and careful physical examination are needed to estimate the status of the thin soft-tissue envelope. The demarcation of soft-tissue necrosis often takes up to 10 days. Thus, early open reduction and internal fixation of the pilon fractures should be done only in selected cases.

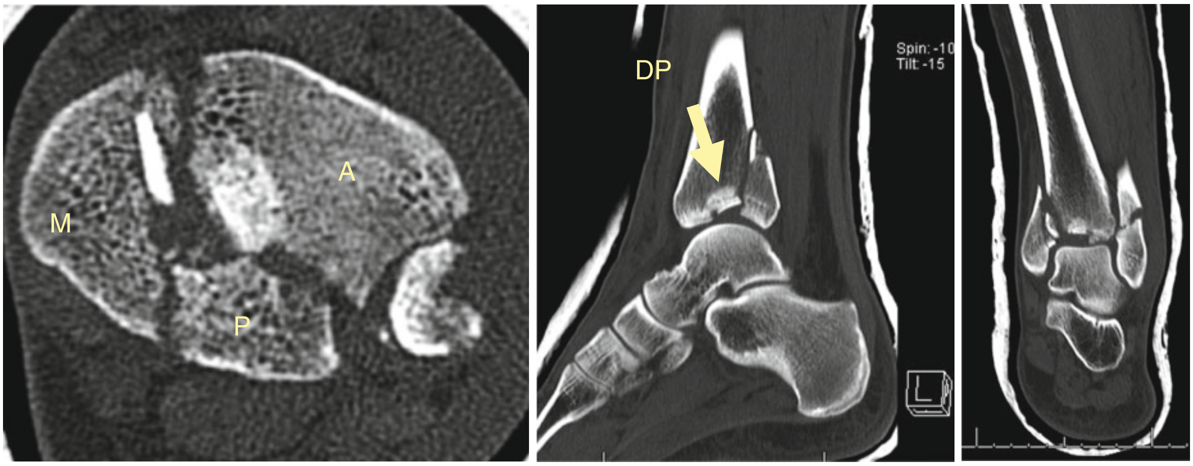

Fig. 27.3 Anterior, posterior, and medial fragments are seen in the CT scan as well as a central articular fragment called a "die-punch" fragment

The most important findings are:

- Pain and displacement
- Soft-tissue breakdown
- Fracture blisters (clear to blood filled)
- Closed or open fractures
- Acute compartment syndrome

Soft tissue injury, associated with closed fractures, is classified by Tscherne and Oestern [30]. They divided the level of injury into four categories. Soft tissue injury, associated with open fractures, is classified by Gustilo and Anderson [12], the standard classification for all open fractures.

27.5.2 Imaging

Preoperative imaging is necessary to allow for careful surgical planning of tibial pilon fractures. The plain radiograph allows an overview of the fracture pattern itself and is required to assure adequate closed reduction. Computed tomography is important to understand all the aspects of the fracture pattern [29]. The following aspects should be examined to allow for adequate surgical planning:

1. Extension of the fracture:
   (a) Intra- or extra-articular
   (b) Diaphyseal extension (length of osteosynthesis)
   (c) Metaphyseal impaction (need for bone grafting)
2. Involvement of the medial, lateral, or posterior column
3. Topography of articular involvement and/or impaction (influence on the surgical approach)
4. Course of split fracture (approach of the lag screw)
5. Fracture of the fibula (shortening and rotation)
6. Soft-tissue involvement (e.g., incorporation of air)

27.6 Associated Injuries

The tibial pilon fractures are often associated with the following injuries:

- Fracture of the tarsus
- Contralateral limb injury
- Neurological deficits
- Vascular deficits
- Bone and soft-tissue loss
- Fracture of the spine and the pelvis

27.7 Management of Treatment

Urgent closed reduction in cases of displacement of the ankle should be performed on an emergent basis. Early stabilization by splinting is necessary to avoid further soft-tissue damage. Depending on the injury pattern and its severity, an urgent surgery with operative reduction and external fixation should be prepared. The main objectives of the initial treatment of tibial pilon fractures are the following:

- Acquire axial alignment after closed reduction
- Achieve anatomical reduction of the joint surface (ligamentotaxis versus open reduction)
- Need for bone grafting in case of impaction or comminuted fractures

- Avoid further damage and respect soft-tissue envelope
- Avoid superficial or deep infection
- Restore joint stability
- Pain-free mobility and functionality

In severe cases, a good or excellent result is not attainable because of the high degree of articular involvement.

27.7.1 Nonoperative Management

The treatment of tibial pilon fractures is predominated by the operative procedure. If ligamentotaxis does not reduce the articular fragments, the closed reduction failed and open reduction is indicated after soft-tissue recovery. In case of nondisplaced fractures, such as A1, B1, or C1 AO types, the nonoperative management is feasible. The acceptance of articular fragment displacement is low (gap <2 mm and offset <1 mm tolerated). A close follow-up for secondary displacement is mandatory. Weight bearing should be restricted for 8–10 weeks. Percutaneous or limited open reduction may be combined with cast immobilization. However, if the stability of the reduction is uncertain, an external fixator should be used instead of a cast.

27.7.2 Operative Management

A note of caution: Do not operate through a compromised soft-tissue envelope, particularly in the case of blood-filled blisters in diabetic patients.

27.7.2.1 Open Reduction and Plate Fixation

Rüedi and Allgöwer established the following guidelines [24]:

1. Open reduction and internal fixation (ORIF) of the fractured fibula
2. Reconstruction of the articular surface
3. Bone-graft implantation if necessary
4. Internal fixation by plate osteosynthesis

These guidelines follow the AO principles of anatomic reduction, rigid stabilization, and early mobilization. The *posterolateral approach* to the fibula is used for its ORIF (Fig. 27.4). The fibular nerve must be respected. In case of comminuted fracture, a bridging plate is used to ensure the alignment (length, rotation, axis). If the soft-tissue overlying the fibula is compromised, ORIF of the fibula should be delayed. The reconstruction of the articular surface is reached by an *anteromedial approach*. These articular fragments cannot be reduced by closed reduction and ligamentotaxis. If a two-incision approach is selected, a skin bridge of 7 cm should be maintained (Fig. 27.4). The open reduction of the articular surface often requires bone graft transfer. The following osteosynthesis aims at a sufficient stabilization. Many authors investigated the outcome after this procedure and concluded there were difficulties with wound healing, especially after high-energy trauma. Free tissue transfer was frequently required [7, 16, 27, 31, 33]. Therefore, a staged protocol has evolved over time to improve overall results of this severe injury.

27.7.2.2 Delayed Open Reduction and Internal Fixation (Staged Protocol)

Several authors have recommended delayed and staged protocols for the treatment of the complex injuries of the tibial pilon [2, 18, 26].

Closed Tibial Pilon Fractures

Closed soft-tissue envelopes can imply severe tissue trauma. Primary closed reduction, external fixation, and ligamentotaxis may be useful. Delayed open reduction in a second surgical intervention follows ideally within 10–14 days after trauma. The recovered tissue envelope mainly tolerates an extensive surgical treatment. Signs of recovery are skin wrinkling and the healing of clear- or blood-filled fracture blisters.

Extensive Opened Tibial Pilon Fractures

The extensive damage of the soft tissue in open fractures has to be respected. There is a multiple-staged procedure recommended to achieve the most predictable result (Fig. 27.5).

1. Initial surgery
   (a) Debridement
   (b) Jet-lavage
   (c) Necrectomy
   (d) External fixator
   (e) K-wires if necessary (*external and limited internal fixation*)
   (f) ORIF of the fibula (*external fixation and limited plating*)
2. Second-look surgery in early damage control management
   (a) Recommended after 48 h
   (b) Further debridement

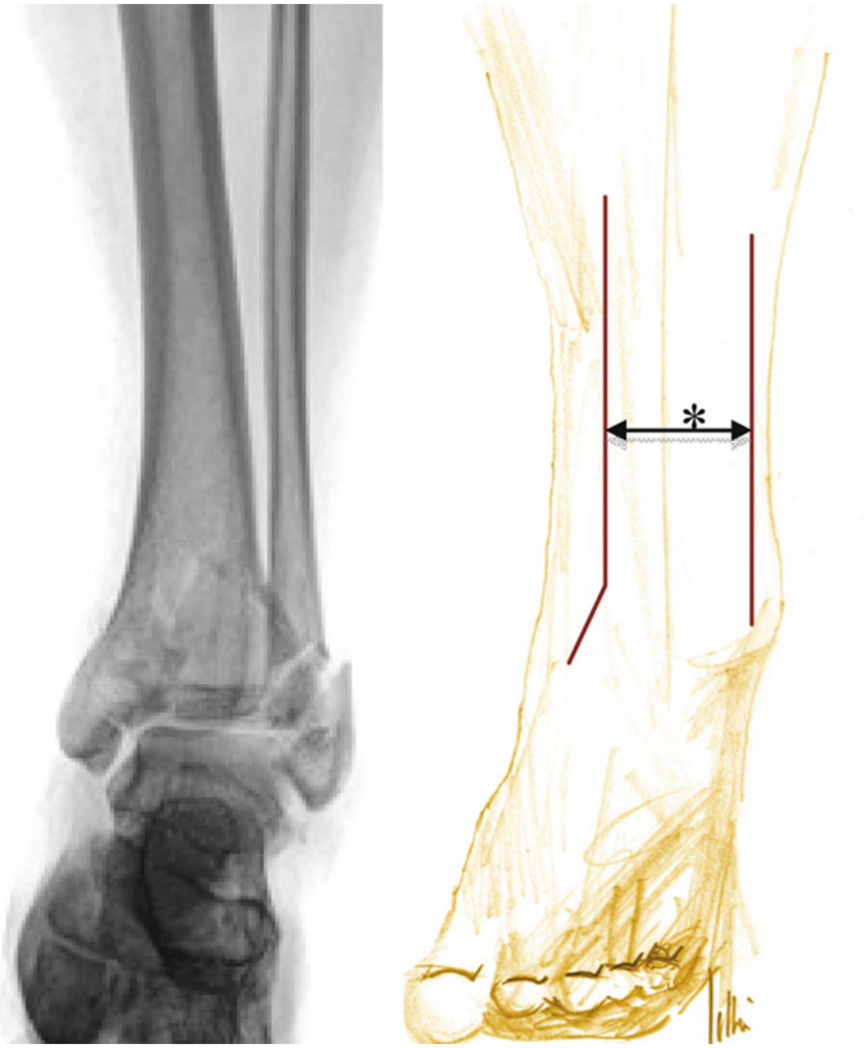

Fig. 27.4 Fibular skin incision with *posterolateral approach* and classical *anteromedial approach* to the tibial pilon; (*) a minimum of 7 cm skin bridge should be maintained to avoid devascularization of the muscle-skin flap

   (c) Incipient reconstruction of the articular surface
   (d) Coverage of areas of bared bone by plastic surgery
3. Third-look surgery
   (a) Staged treatment by or with percutaneous, limited open, or open reduction
   (b) Definite stabilization of the articular bone block
   (c) Bridging of the comminuted fracture zone

27.7.2.3 Minimally Invasive Plating Osteosynthesis (MIPO)

Minimally invasive techniques of plating have been further developed. After closed reduction of the fracture by ligamentotaxis, the ostheosynthesis is inserted through limited incisions. Minimally invasive approaches decrease impaired blood supply in comparison to the open approach [6]. Borens et al. described a two-stage minimal incision approach that obtained fewer wound healing complications while maintaining the articular reduction by medial percutaneous plating [5].

27.7.2.4 Hybrid External Fixation

The hybrid external fixator (hybrid frame) combines tensioned wires in the epiphyseal fragment and diaphyseal half-pins in the same construct.

1. *Indications and advantages*:
   (a) AO type A, type C1, type C3 fracture
   (b) Distinctive soft-tissue involvement
   (c) Noninvolvement of the tibiotalar and subtalar joint

Fig. 27.5 A case of a 44-year-old male patient, who was hospitalized after he fell of a height of 2 m at work. The immediate application of a spanning external fixator was followed by a delayed surgery with ORIF after 5 days and soft tissue consolidation. Autologous cancellous bone graft was used to replace metaphyseal bone loss after reduction. Due to a weak soft tissue envelope and a diabetic metabolism, a free flap recovery was necessary after several debridements and an unsuccessful medial MESH graft plastic. Despite satisfactory reduction and bone consolidation, a posttraumatic arthrosis followed and was clinically evident after 6 months

Fig. 27.5 (continued)

2. *Disadvantages*:
   (a) Sufficient surgical experience is required
   (b) No adequate fixation in comminuted fractures
   (c) No adequate fixation in fractures with tibiotalar instability
   (d) Limited reduction
   (e) Articular infection
   (f) Tendinous, neurological, and vascular damage ("safe" corridor wire placement) [32]

27.7.2.5 Primary Arthrodesis

Primary arthrodesis has been suggested for cases of tibial pilon fractures with severe comminution. Nevertheless, adequate soft tissue coverage is crucial to allow for adequate fusion.

27.8 Complications and Prognosis

Poor results have been reported in severe fracture patterns. A correlation between the degree of classified fracture type and the long-term outcome has been demonstrated. The articular reduction is the most important predictor of posttraumatic arthritis [10, 20]. The early and late complications are associated with the soft-tissue damage from the injury, the degree of fragment displacement, and articular surface involvement.

27.8.1 Early Complications

- Wound breakdown
- Infection
- Osteitis

27.8.2 Late Complications

- Malunion
- Nonunion
- Posttraumatic arthritis
- Malalignment

27.8.3 Clinical Outcome and Prognosis

A number of studies investigated the long-term clinical outcome after tibial pilon fractures [15, 19] using established measurements such as the SF-36. They concur that patients who suffered a pilon fracture have significantly poorer health scores than the average population after 3–5 years. A high percentage had to change their jobs or were disabled as result of the tibial pilon fracture. Osteoarthritis was present in over 50 % of the cases. The arthritis appeared after 2 years post trauma, but the clinical outcome was poorly correlated.

Conclusion

Tibial pilon fractures are characterized by the involvement of the articular surface and an association with severe soft-tissue damage. Development of staged protocols for surgery, the improvement of implants, and modified surgical approaches caused an improvement in outcome of this injury. The long-term expectations may be limited due to the degree of initial cartilage damage and the limited options for soft tissue coverage.

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Foot and Ankle Injuries

28

Susanne Rein, Ken Jin Tan, Stefan Rammelt,
and Hans Zwipp

> Man's foot is all his own. It is unlike any other foot. It is the most distinctly human part of the whole of his anatomical make-up.
>
> Wood Jones (1944) [1]

The goal of this chapter is to further the understanding of pathomechanisms, performing diagnostics and reconstructing of injured feet, and to demonstrate ways to treat malunions and nonunions. Regaining anatomic joints if possible and rebuilding the normal shape of the foot, even by fusion of joints, is a safe way to avoid pain and to restore function.

28.1 Anatomy of the Foot

The human foot contains 28 bones and is divided into three parts: the forefoot, the midfoot, and the hindfoot (Fig. 28.1) [3, 4].

28.1.1 Forefoot

The forefoot contains the five metatarsals and toes with two sesamoids under the first metatarsal head and an inconstant sesamoid beneath the first interphalangeal joint. Six weight-bearing surfaces are located at the metatarsophalangeal level (two sesamoids and four lesser metatarsal heads) and five weight-bearing surfaces are located under the distal phalanges in a normal foot.

The metatarsals are short tubular bones with a base, shaft, neck, and head. The heads of the metatarsals are strongly connected by the intermetatarsal ligaments. The fifth metatarsal has a tuberosity at its base, where the plantar aponeurosis, the peroneus brevis, and the peroneus tertius tendon insert.

The first toe has two phalanges and the other four toes have three phalanges. The first metatarsal is slightly shorter, broader, and more mobile than the three middle metatarsals, and normally bears as much as one-third to one-half of the body weight through the forefoot and plays a key role in the gait cycle. The metatarsophalangeal joints are ellipsoidal joints, but only the first and fifth rays allow flexion/extension and ab-/adduction. The joint capsules are strengthened by collateral ligaments on either side.

The two sesamoids at the first metatarsophalangeal joint are well embedded in the capsuloligamentous complex; the medial (tibial) sesamoid is larger than the lateral (fibular) sesamoid, corresponding to its more important role in weight bearing within the medial sulcus of the metatarsal head.

The sesamoids are held together by the strong intersesamoid ligament and the plantar plate, which is firmly attached at the base of the proximal phalanx and loosely attached at the neck of the metatarsal via the capsule. The sesamoids are located within the two slips of the flexor hallucis brevis tendon. The abductor hallucis tendon inserts at the medial sesamoid, the adductor hallucis tendon at the fibular sesamoid.

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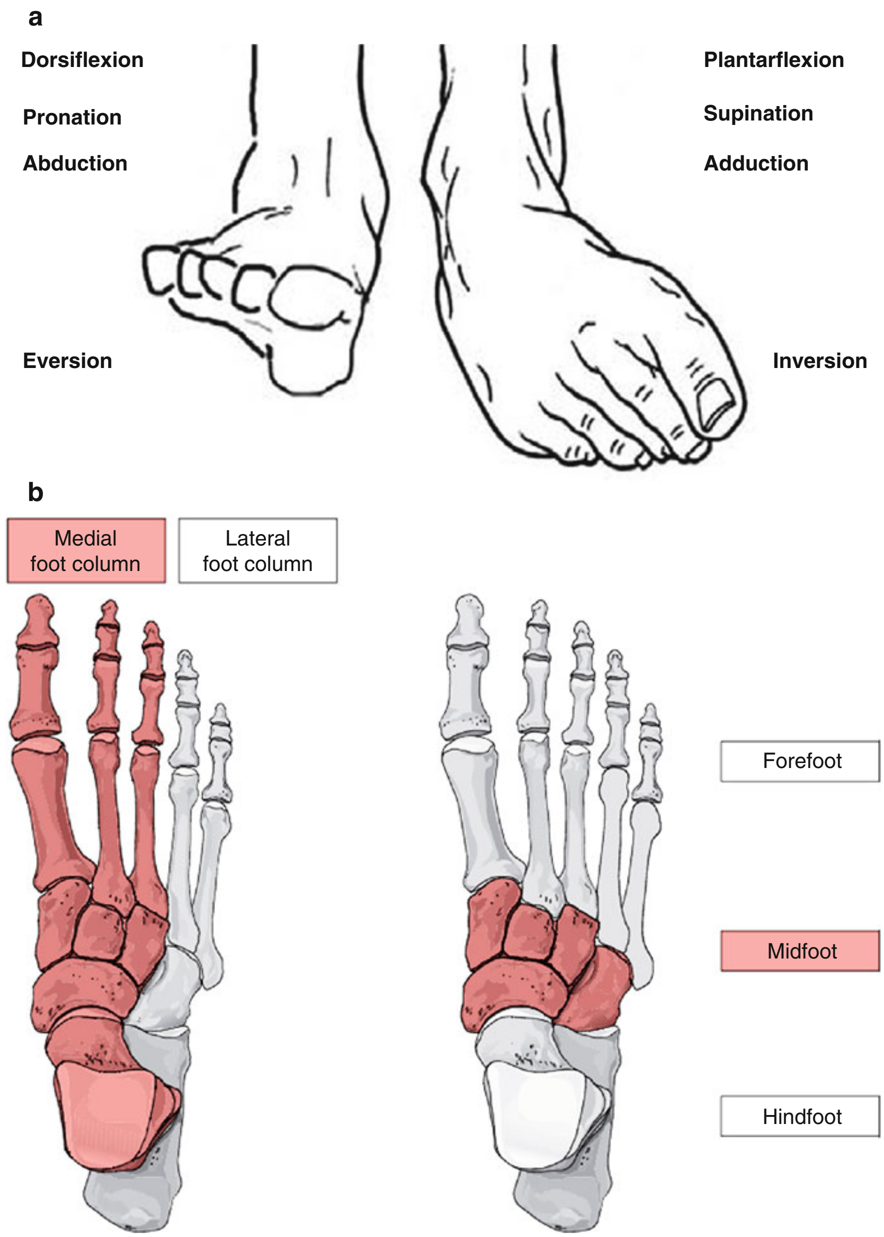

Fig. 28.1 (**a**) Components of the "clamp jaw movement" as three-dimensional overall movement of the ankle and subtalar joint as eversion and inversion. (**b**) Functional-anatomical classification of the foot (From Rammelt and Zwipp [2])

Strong collateral ligaments together with the capsule and the extensor elements contribute to a high degree of stability at the first metatarsophalangeal joint. The dorsal capsule of the metatarsophalangeal joint is usually structurally weak. The plantar capsule is a strong specialized structure with a firm attachment to the base of the proximal phalanx (plantar plate) and a thinner, more flexible attachment to the undersurface of the first metatarsal head. The interphalangeal joints are hinge joints with strong collateral ligaments. The plantar fascia originates at the anterior weight-bearing tubercle of the calcaneus, spans the plantar aspect of the midfoot and the longitudinal arch, and attaches to the plantar skin beneath the toes and to the base of the proximal phalanges. The shape of the medial arch is maintained by the bony contour of the foot, the strong inferior capsular ligaments of the midfoot joints, the tarsometatarsal joints, the posterior tibial tendon, and the plantar fascia.

28.1.2 Midfoot

The five midfoot bones are the medial, intermediate, and lateral cuneiforms, the navicular, and cuboid, situated between the tarsometatarsal (Lisfranc) and the midtarsal (Chopart) joints. Motion in the medial column takes place primarily at the talonavicular joint, which is an essential joint. The length of the lateral column is held by the anatomical shape of the calcaneocuboidal joint and the bony structures. The Lisfranc joint is formed proximally by the three cuneiforms and the cuboid and distally by the metatarsal bases. The medial three metatarsals articulate with the corresponding cuneiforms, whereas the two lateral metatarsals articulate with the cuboid.

The second metatarsal base is set back proximally between the medial and lateral cuneiforms and acts as a keystone of the transverse arch of the foot. The oblique Lisfranc ligament originates from the medial cuneiform and inserts at the base of the second metatarsal, whereas a ligament between the first and second metatarsal bases is absent, explaining the frequent isolated dislocation at this area. The range of motion of the Lisfranc joint at the first and fifth ray is 15–20° in the sagittal plane, whereas the middle rays are amphiarthroses that allow only a little motion. The neurovascular bundle, containing the dorsalis pedis artery and the deep peroneal nerve, runs between the first and the second ray and is therefore endangered during reduction of Lisfranc injuries.

28.1.3 Hindfoot

The hindfoot consists of the talus and calcaneus with the essential ankle and subtalar joints and a group of complex ligamentous attachments. The ankle consists of the tibiotalar joint, the fibulotalar joint, and the distal tibiofibular syndesmosis. The triceps surae attaches to the calcaneal tuberosity, exerting a strong plantar flexion force on the hindfoot. Rotation of the foot in relation to the talus is restricted by attachments of the calcaneonavicular and talonavicular ligaments and the posterior tibial tendon at the midfoot. Working together, the ankle and subtalar joint adapt the foot to uneven surfaces and maintain a stable bipedal stance and gait even with only one foot on the ground.

28.2 Physiology

The bony structure of the foot comprises three main arches, the medial and lateral longitudinal arches and the transverse arch. These arches are formed by the tarsal and metatarsal bones and maintained by a series of ligaments and tendons. The plantar fascia also supports the longitudinal arch and runs from the calcaneal tuberosity to the bases of the proximal phalanges. The plantar tissues of the foot are highly specialized for weight bearing, and consist of the plantar fat pad, which is made up of a specialized collection of adipose tissue within a fibrous framework in a whorled pattern.

The foot may also be divided into the medial and lateral columns. The medial column comprises the navicular, cuneiforms, and the one to three metatarsals. The more mobile lateral column comprises the cuboid, the fourth and fifth metatarsals (Fig. 28.1).

In general, the joints of the foot and ankle are highly conforming joints and any step-off after a fracture can lead to large differences in load bearing pressures and subsequent arthritis. Dorsiflexion and plantarflexion are referred to the ankle joint, whereas pro- and supination are assigned to the subtalar joint. The combination of dorsiflexion, pronation, and abduction results in eversion, whereas plantarflexion, supination, and adduction result in the inversion of the foot (Fig. 28.1).

28.3 Principles of Clinical Examination

A clinical history should include questions on the mechanism of trauma. A complete history on the duration, location, and nature of the pain, including aggravating and relieving factors, should be sought.

The shoewear of the patient should be examined. Inspection of the forefoot, midfoot, and hindfoot for deformities and range of motion of the ankle, subtalar, and midfoot joints should be noted. The sole should also be inspected for callosities and ulcers. It is important to examine the feet in a weight-bearing position. The gait of the patient should be observed and a gait analysis could be done in addition. The neurovascular status of the foot should also be examined.

28.3.1 Technical Diagnostic Procedures

The reader is referred to the respective subchapters for information on technical diagnostic procedures.

28.3.1.1 Organ-Specific Radiology

Standard radiographs of the ankle joint include anteroposterior with 20° internal rotation of the leg, so-called "mortise view," and lateral views (Fig. 28.2). Standard radiographs of the foot include dorsoplantar (with 20° craniocaudal tilted X-ray tube for the Lisfranc joint and with 30° craniocaudal tilted X-ray tube for the Chopart joint), oblique and lateral views [4–6] (Fig 28.2). Load-bearing views for chronic conditions are recommended as many subtle injuries can only be appreciated under weight bearing [4, 6]. There should be generous use of computed tomography (CT) scans in any suspected fracture at the hindfoot or midfoot. CT scans also allow three-dimensional (3D) reconstructions, which are helpful for preoperative planning [7] (Fig 28.3). Magnetic resonance imaging (MRI) is useful for subacute and chronic conditions, especially tendon and ligament pathology, avascular necrosis, etc. [6]. Ultrasound and Technetium-99m (Tc) bonescans may also be useful for investigation of painful conditions and for supplementing information provided by X-rays and CT scans.

28.4 Fractures of the Talus

The talus (taxlus = tacillus = die) received his name from Roman soldiers, who used the tali of horses as dice because of their manifold facets. This bone connects the ankle joint with the foot, articulating at three levels: ankle joint, subtalar joint, and talonavicular joint. Because fractures of it were so often seen in pilots during the First World War, the talus is well known as "aviator's astragalus."

28.4.1 Anatomy

The talus is divided into three main parts: the body, the neck, and the head. It has no insertions of muscles or tendons. About two-thirds of the talus is covered by articular cartilage. The posterior process of the talus can exist as an accessory bone (os trigonum) in half of all cases and has to be distinguished from fractures of the posteromedial tubercle [8]. The posterolateral and posteromedial tubercles of the posterior process form a groove for the flexor hallucis longus tendon.

The lateral process or fibular process is a triangular protrusion of the talar body that makes up the lateral portion of the posterior subtalar facet. The talocalcaneonavicular joint, also known as "coxa pedis," represents the connection to the midfoot. The neck of the talus lies between the body and head. It is most susceptible to fractures and lies directly over the sinus tarsi and tarsal canal. The sinus tarsi separates the subtalar from the talocalcaneonavicular joint. The sinus tarsi contains the following ligaments: the inferior extensor retinaculum with its lateral, intermediate, and medial roots, the talocalcaneal oblique ligament, also known as the "cervical ligament," and the canalis tarsi ligament [9].

The lack of periosteal attachments and large area of articular cartilage make the talus prone to avascular necrosis. Branches of the posterior tibial, dorsal pedis, and peroneal arteries contribute to the tenuous blood supply of the talus [10, 11]. The posterior tibial artery gives off the artery to the tarsal canal. This branch also gives off a deltoid branch that supplies the medial talar body. The dorsal pedis artery runs dorsally over the superior surface of the neck and supplies the talar head. In addition, the perforating peroneal artery gives off the artery of the tarsal sinus. The arteries of the tarsal canal and sinus are the main blood supply for the inferior neck and talar body [10].

28.4.2 Physiology/Pathophysiology

The talus articulates with three main joints, the ankle, subtalar, and Chopart joints. Talar fractures can lead to subluxation or dislocation of any or all three joints and can also predispose all three joints to subsequent arthritis.

28.4.3 Organ-Related Disease: Definition of the Disease

Central fractures are fractures of the talar body and talar neck. Peripheral fractures include fractures of the talar head as well as lateral and posterior processes.

Fig. 28.2 Radiological parameters for assessing the correct position of the ankle joint in the anteroposterior view with 20° internal rotation (**a**), so-called "mortise view" and the lateral view (**b**). *1* Symmetrical joint space, *2* Weber's nose, *3* Weber's ball, *4* "ligne claire" according to Chaput (<6 cm). Standard radiographs of the foot include dorsoplantar (**c**), an oblique view with a 45° tilted tube (**d**) and lateral views (**e**). The first and second metatarsalia are well seen in the dorsoplantar, the third, fourth, and fifth metatarsalia in the oblique view. A distance of more than 3 mm between the metatarsalia I and II in the dorsoplantar view indicates an injury of the Lisfranc ligament. The lateral view shows the S-shaped "Cyma line" of the Chopart joint. Any dorsal deviation of the metatarsalia in the lateral view is suspicious for an instability of the Lisfranc joint

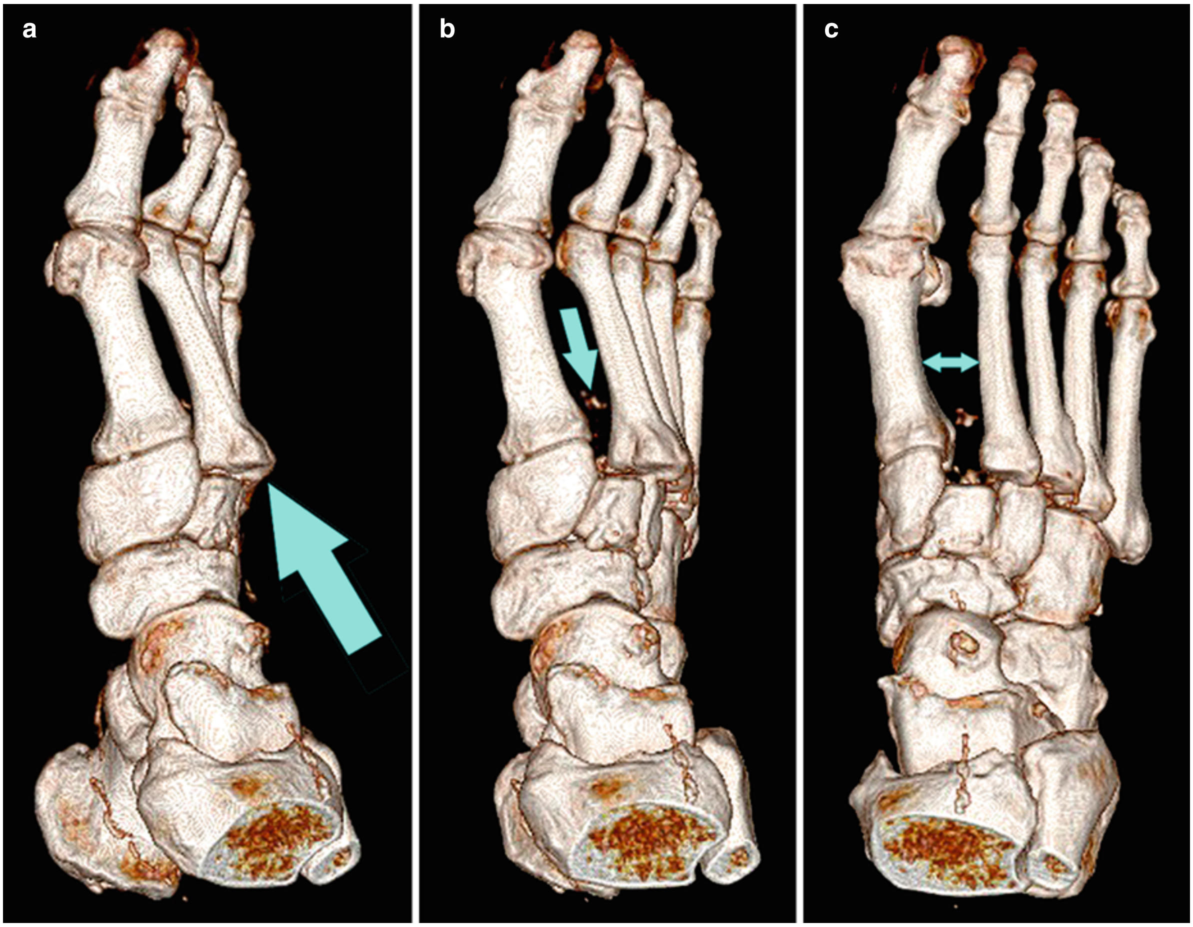

Fig. 28.3 A Lisfranc dislocation fracture is shown as an example for a 3D-reconstruction after CT scan of a foot (**a**–**c**), which is helpful for preoperative planning. Dorsal deviation of the metatarsalia II and III are clearly visible (*arrow* in **a**). The "fleck sign" represented as a bony avulsion of the distal Lisfranc ligament attachment is seen (*arrow* in **b**). The distance between metatarsalia I and II is increased (*arrow* in **c**)

The distinction between distal body fractures and neck fractures is defined by the position of the fracture line in the sagittal CT scan. If the fracture line lies behind the lateral process, it is a corpus fracture; otherwise, it is a neck fracture [12].

Neck fractures are classified by the Hawkins classification, which has a direct correlation between the degree of talar dislocation and the risk of avascular necrosis [13] (Fig. 28.4):

- Type I: undislocated talar neck fractures
- Type II: dislocation at the subtalar joint
- Type III: dislocation at the subtalar and ankle joints
- Type IV: dislocation at the subtalar, talonavicular, and ankle joints (added by Canale and Kelly [14]).

The Marti and Weber classification includes all peripheral and central talus fractures [15] (Fig. 28.4):

Type I: peripheral and osteochondral fractures including head fractures
Type II: undislocated central fractures of the talar head and the neck
Type III: central fractures (head and neck) with dislocation at the subtalar or ankle joint.
Type IV: central fractures (head and neck) with dislocation at the subtalar and ankle joints, including comminuted fractures and dislocation at the talonavicular joint.

The AO/ICI (integral classifications of injuries) classification of the foot [16] includes all central and peripheral fractures:

Extra-articular (type A),
Intra-articular (type B)
Dislocation fractures (type C)
Pure dislocation forms (type D)

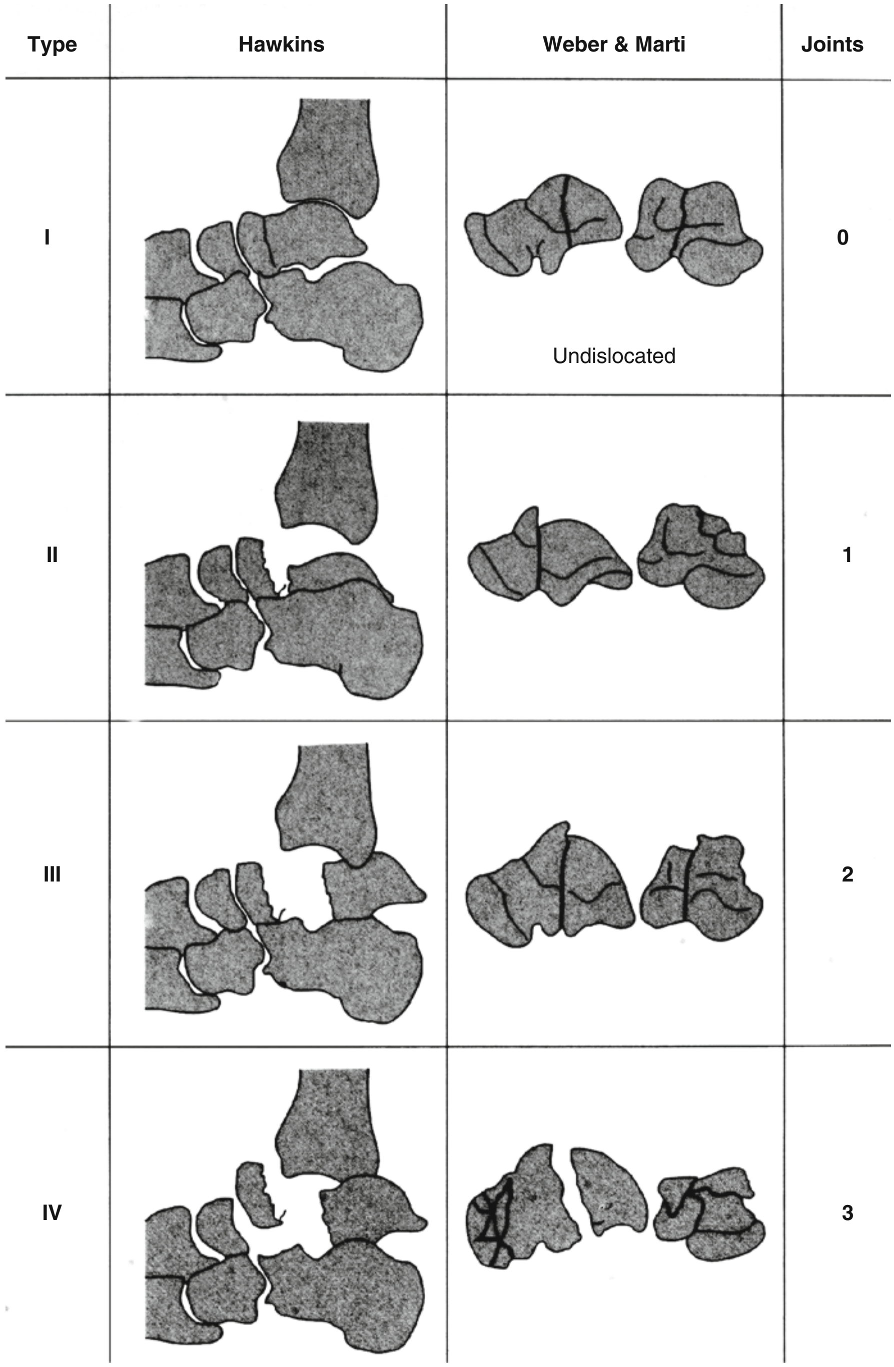

Fig. 28.4 Classifications according to Hawkins as well as Marti and Weber are shown. The risk of post-traumatic arthritis or avascular necrosis increases progressively with dislocation of the talar neck and body (From Zwipp [4])

The subgroups (1–3) define the number of joints involved (tibiotalar, subtalar, and talonavicular).

Subtalar dislocations, "Luxatio pedis sub talo," are classified into medial and lateral types. The rare complete dislocation of the talus in the ankle joint after rupture of the medial and lateral collateral ligaments is termed "Luxatio pedis cum talo" [4]. Total talar dislocations, "Luxatio tali totalis," describe the extreme form of the talar enucleation out of all three joints [4, 17].

Transchondral dome fractures of the talus were first described by Kappis in 1992 [18]. The Berndt and Harty classification divides osteochondral talar fractures into four types [19] (Fig. 28.5):

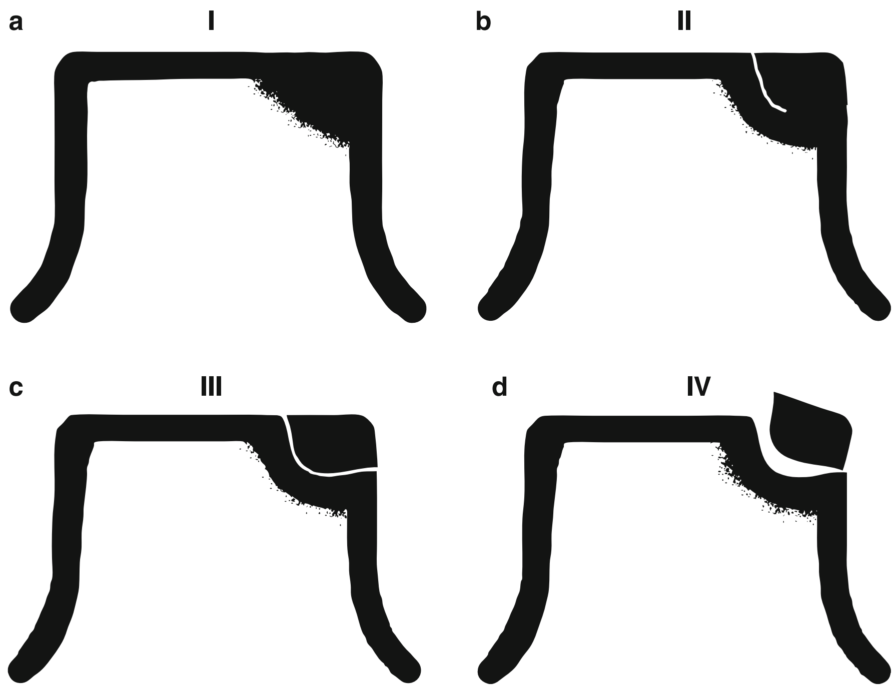

Fig. 28.5 Osteochondral talar fractures according Berndt and Harty [19], with stage I as a focal cartilage compression (**a**), stage II as a partially detached osteocartilaginous fragment (**b**), stage III as a completely detached osteochondral fragment (**c**), and stage IV as a separate nonviable displaced bone fragment (**d**)

Phase I: focal cartilage compression
Phase II: partial separation of the osteochondral fragment
Phase III: complete separation of the osteochondral fragment
Phase IV: dislocated osteochondral fragment

As newer imaging technologies (arthroscopy, CT, MRI) have emerged, a variety of additional classification systems have been proposed [20–24].

28.4.4 Epidemiology/Etiology

Talar fractures comprise between 0.09 and 0.62 % of all bony injuries [25] and 2–3 % of all fractures of the foot [4]. The vast majority are high-energy fractures and result from a fall from a height or from motor vehicle accidents. A high percentage of patients with talar fractures are polytraumatized patients [4]. Fifteen percent of all talus fractures are open [14]. Fractures of the talar neck make up half of all talar fractures [26, 27]. The mechanism of this type of fracture is a forced dorsiflexion of the foot together with an axial impaction force [28]. Thirteen to twenty-three percent of all talar fractures are fractures of the body, which are produced by forced plantarflexion in combination with axial impaction and rotation at the time of the accident [27, 29, 30]. Fractures of the talar head are rare and are mostly associated with a dislocation at the Chopart joint. They are caused by forced abduction or adduction of the forefoot with simultaneous axial compression of the foot [31].

Peripheral fractures are frequently associated with subtalar dislocations. Forced dorsal extension combined with inversion of the foot causes lateral process fractures [32] which are often seen in snowboarding accidents [33, 34]. Posterior process fractures are caused by maximum plantarflexion with impingement between the posterior edge of the tibia and the calcaneus, for example, in soccer players or dancers, and have to be distinguished from an os trigonum [35]. Osteochondral fractures are produced by inversion of the foot and are mostly located at the centromedial or centrolateral aspect of the talar dome [36].

28.4.5 Symptoms

The main clinical findings are deformity, swelling, crepitation, and pain over the ankle region. Sometimes a displaced fragment is palpable at the dorsum of the foot. Protrusion of dislocated fragments can result in skin necrosis. The patient is unable to bear weight with the affected leg. Pain with peripheral fractures is often referred over the ligaments, which is why these injuries are often initially overlooked in about half of all cases [37]. Osteochondral fractures are misdiagnosed in up to 75 % as ankle sprains [38]. These patients present with chronic ankle pain and instability, associated with swelling, pain, and weakness about the ankle. Symptoms are exacerbated by prolonged weight-bearing or high-impact activities such as running or jumping sports [39].

28.4.6 Diagnosis

28.4.6.1 Recommended European Standard Diagnostic Steps of Investigation History of Accident

Determination of the history of accident, inspection, palpation, control of motion, sensation, and perfusion of the foot are basic steps of the clinical investigation. Standard radiographs include anteroposterior and lateral views of the talus. The dorsoplantar view with 15° pronation and 75° cephalad tilted tube from the table top, so-called "Canale view," reveals subtle varus malposition of the talar neck as well as the involvement of the talonavicular joint [14]. The Broden view with 45° internal rotation of the leg and a 40° caudally tilted tube demonstrates the lateral process and the subtalar joint. CT scanning in coronal and sagittal 1-mm sections is recommended for specific diagnosis, operative planning, and identification of additional injuries, which cannot be detected with conventional radiographs, for example, peripheral fractures, comminution, and subluxation.

28.4.6.2 Additional Useful Diagnostic Procedures

Persistent pain after subtalar dislocation or lateral ligament injury of the ankle warrants further investigation by CT scanning to exclude peripheral fractures or MRI to exclude osteochondral fractures. MRI is not indicated in acute injuries, because of the bone marrow edema, but is useful for the evaluation of the vitality or revascularization of the talar dome post-fracture.

28.4.7 Therapy

28.4.7.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

The rare undisplaced fractures of the talar body and neck (type A, Hawkins I, Marti II) may be treated in a non-weight-bearing, below-the-knee cast of the involved leg for 6–12 weeks [14]. However, a percutaneous screw transfixation allows early function after treatment and avoids a secondary displacement in such cases.

Conservative therapy of undisplaced fractures is associated with arthritis in 30 % of all cases [40], because a small amount of joint incongruency can cause significant weight redistribution between the joint facets [41]. Conservative treatment attempts for Hawkins II fractures have an unacceptably high rate of redislocations and unsatisfactory results [14]. Nonoperative treatment attempts for peripheral fractures, particularly lateral process fractures, often causes painful nonunion or malunion, which may require a subtalar arthrodesis [37, 42].

Osteochondral fractures of stage I and II (Berndt and Harty classification) can be subjected to a trial of conservative treatment [19, 43]. Stage I injury is subjected to functional therapy with limitation of sporting activity and a short duration of non-weight-bearing of the affected foot. Stage II injury requires immobilization in a cast or orthosis for 6 weeks.

28.4.8 Surgery: Recommended European Standard Surgical Procedures

Displaced talus fractures should undergo open reduction and internal fixation as early as possible [44]. Emergent reduction of fracture dislocations reduces the fragment pressure on the skin and avoids skin necrosis [13, 14, 25, 45]. If the physical status of a patient (e.g., polytrauma) does not allow primary internal fixation, gross reduction and joint transfixation is carried out. During a second operation, anatomic reduction and definitive fixation are performed when the patient is stable [25]. Attempts at closed reduction frequently fail. Fracture dislocations of the talus require emergent reduction to avoid further compromise of the soft tissue and blood supply. There is no evidence that definitive internal fixation of all displaced central talar fractures within a few hours is required [25] and definitive fixation may be staged (Fig. 28.6).

28.4.9 Differential Diagnosis

Osteochondral fractures should be differentiated from osteochondritis dissecans, which is more frequently posteromedial, may not have a history of trauma, and carries a worse prognosis [38]. CT scans will help in identifying associated fractures such as calcaneal fractures.

Fig. 28.6 A patient, who fell after jumping down four stairs, suffered a talus neck fracture, type IV according to Marti and Weber, seen in the anteroposterior (**a**) and lateral (**b**) views. Preoperative CT scan (**c**) revealed a severe comminuted talus fracture and an undislocated cuboid fracture (*arrow* in **c**). Initial treatment included open reduction and osteosynthesis with one screw as well as protection with a tibiometatarsal fixateur externe (**d**, **e**). After the swelling diminished, definitive screw osteosynthesis of the talus was performed via anteromedial, lateral, and posterolateral approaches. The cuboid fracture was stabilized with a plate, and the bony avulsion fracture of the calcaneofibular ligament (*arrow* in **a**) was refixed with a bone anchor (*arrow* in **h**). Postoperative X-rays (**f–i**) show congruent joint surfaces. Hardware removal is not recommended

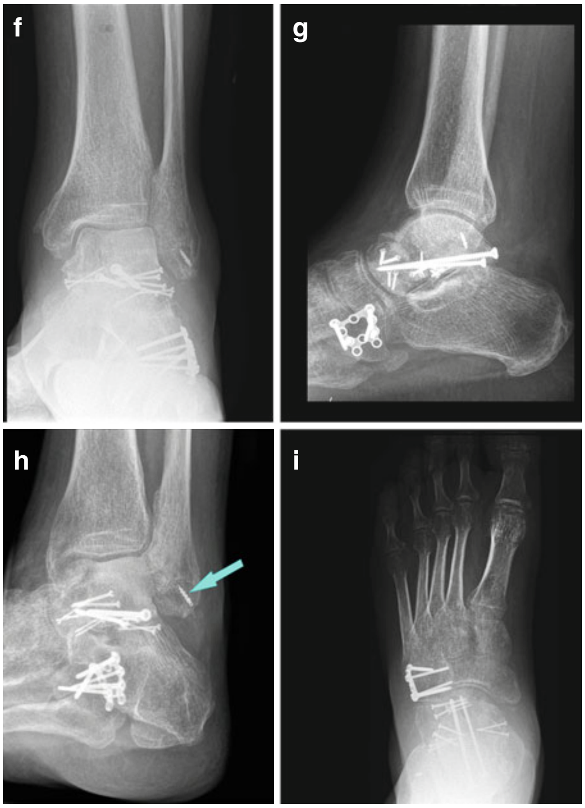

Fig. 28.6 (continued)

28.4.10 Prognosis

Prognosis depends on the degree of initial displacement, joint involvement, and associated soft-tissue injury. Talar head fractures have a better prognosis than talar body or neck fractures because of the better blood supply [46, 47]. Up to 59 % have temporary or persistent complaints after talar body fractures [42]. Excision, curettage and drilling, bone and/or cartilage autografts, and autologous chondrocyte transfer have good to very good medium-term results in about 80 % of osteochondral fractures. Prognosis for talar neck fractures is good to very good for 40–100 % of Hawkins I fractures, 32–80 % for Hawkins II fractures, and 15–55 % for Hawkins III fractures. In principle, open fractures have a poor prognosis [25, 48]. Conservatively treated lateral and posterior process fractures are associated with post-traumatic arthritis of the subtalar joint. Pure ligamentous peritalar dislocations have a favorable prognosis.

Unfavorable prognostic factors are open dislocations, lateral subtalar dislocation, total talar dislocation, accompanying peripheral talar fractures, and cartilage damage at the talar dome as well as associated calcaneal fractures [49].

28.4.11 Complications

Skin necrosis occurs in 11 % after surgically treated talus fractures [50]. Deep soft tissue infections are seen in 5–7 % after open fractures [14, 51]. Osteomyelitis, mostly with septic necrosis, is the most severe complication after complex talar fractures and leads to functional deficits even after successful salvage [52]. Further complications are compartment syndrome and neurovascular injury. Secondary displacement can cause post-traumatic arthritis. The incidence of post-traumatic arthritis varies between 16 and 97 % after fractures and dislocations of the talus [53, 54], but only about one-third become symptomatic [55].

Avascular necrosis is a specific complication of central talus fractures because of the blood supply via the talar neck. The avascular necrosis rate depends on the initial fracture and is reported in the literature for undisplaced talar neck fractures with no dislocation to be 0–12 %, for Hawkins II fractures 0–50 %, and for Hawkins III and IV fractures 30–100 % [56]. The avascular necrosis rate is 10 % for nondislocated talar body fractures, 25 % for dislocated talar body fractures, and 5 % for talar head fractures [57]. The rate of avascular necrosis is 0–10 % after closed and up to 50 % after open medial and lateral subtalar dislocations [58]. The treatment of avascular necrosis is initially conservative, with pain-restricted functional therapy and full weight bearing for at least 16 weeks, which may be followed by a spontaneous recovery after 12–24 months [51, 59].

Collapse of the talar body warrants a corrective arthrodesis of the ankle and/or subtalar joint. The talar head should be preserved to save the function of the important talonavicular joint.

The incidence of nonunion is 10 % [53, 60], caused by initially overlooked fractures or peripheral fractures and early full weight bearing after talar neck fractures. Therapy includes resection of the nonunion, bone grafting, and reosteosynthesis or arthrodesis in cases of symptomatic arthritis [47].

Lateral subtalar dislocations have a high risk of injury to the posterior tibial nerve. Medial and lateral subtalar dislocations can cause tendons irritation with development of post-traumatic tendinitis. Elongation or incarceration of the posterior tibial tendon can cause post-traumatic flat foot.

28.4.12 Exemplary Surgical Procedures

28.4.12.1 Talar Neck and Body Fractures

The anteromedial approach for talar neck and anterior talar body fractures with protection of the blood supply of the posterior talar dome is via the deltoid ligament. An additional osteotomy of the medial malleolus for central fractures of the talar body may be added.

A bilateral approach is required for fracture dislocations, including comminuted fractures and all fractures with involvement of the subtalar joint (lateral process fractures). The lateral approach is performed either anterolaterally or with an oblique incision [55]. A posterolateral approach is useful for dorsally located talar body fractures and posterior process fractures. The posteromedial approach lateral to the posterior tibial neurovascular bundle is rarely required for fractures of the posteromedial tubercle or body. Visualization of the joint surfaces can be facilitated with a medial distractor [4].

The anatomical reduction of the talar axis as well as the joint surfaces is performed under direct visual control. The fragments are fixed temporarily with K-wires. Osteosynthesis with screws provides adequate stability for the most talar fracture types [61] (Fig. 28.7). The screw heads are countersunk near the joint surfaces.

Lag screws should be avoided to prevent shortening or varus malposition of the talar neck [47]. Mini-plate osteosynthesis and autologous cancellous bone grafting are required for large central comminution [55]. Titanium implants are recommended in order to facilitate MRIs in the postoperative period. Anatomical reconstruction is sometimes not possible for severely comminuted fractures. In such cases, the goal of treatment is reconstruction of the anatomical shape of the talus to facilitate secondary arthrodesis of the highly destroyed joint surface after temporary tibiometatarsal external fixation for 10 days [4].

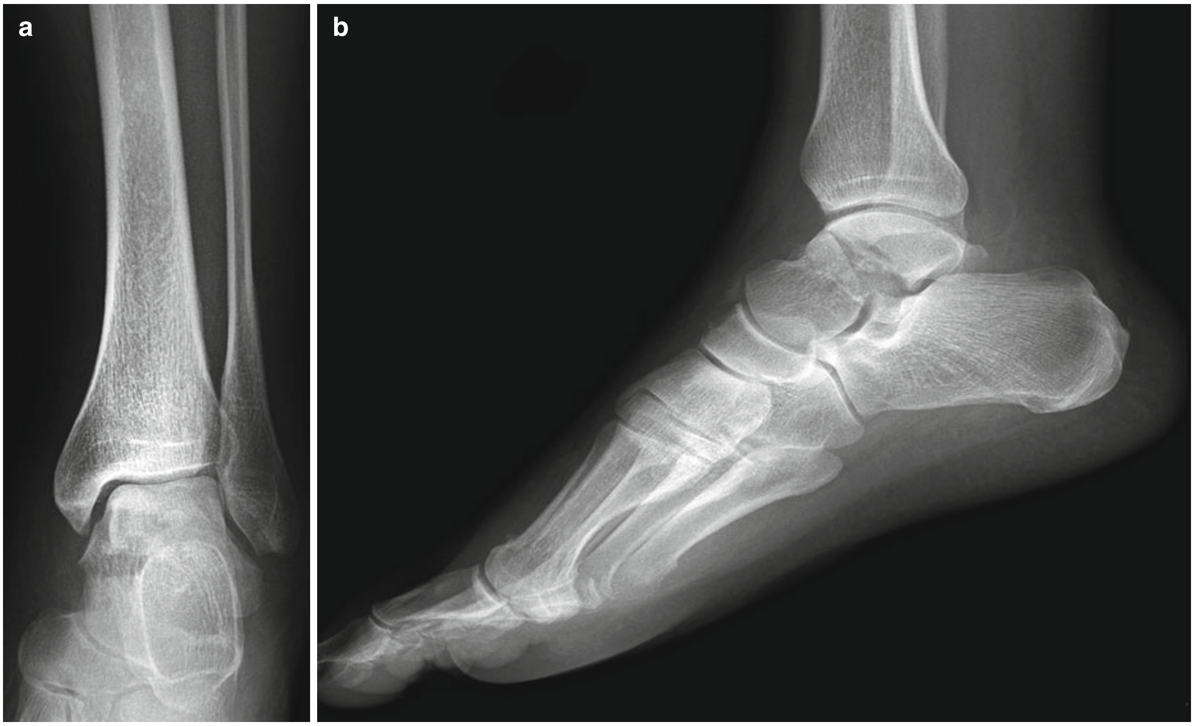

Fig. 28.7 A patient, who fell down from a 6-m-high roof, was injured with a talus fracture type III, according to Marti and Weber, with dislocations in the talonavicular (*arrow* in **e**) and subtalar joints (*arrow* in **d**) seen in the X-rays (**a**, **b**) and preoperative CT scans (**c**, **d**, **e**). Closed reduction and tibiometatarsal external fixation were performed on the day of injury. After soft tissue consolidation, definitive osteosynthesis with six screws was performed via anteromedial and Ollier approaches. Postoperative X-rays (**f**, **g**, **h**) show anatomical joint surfaces and a healed fracture 4 months after surgery

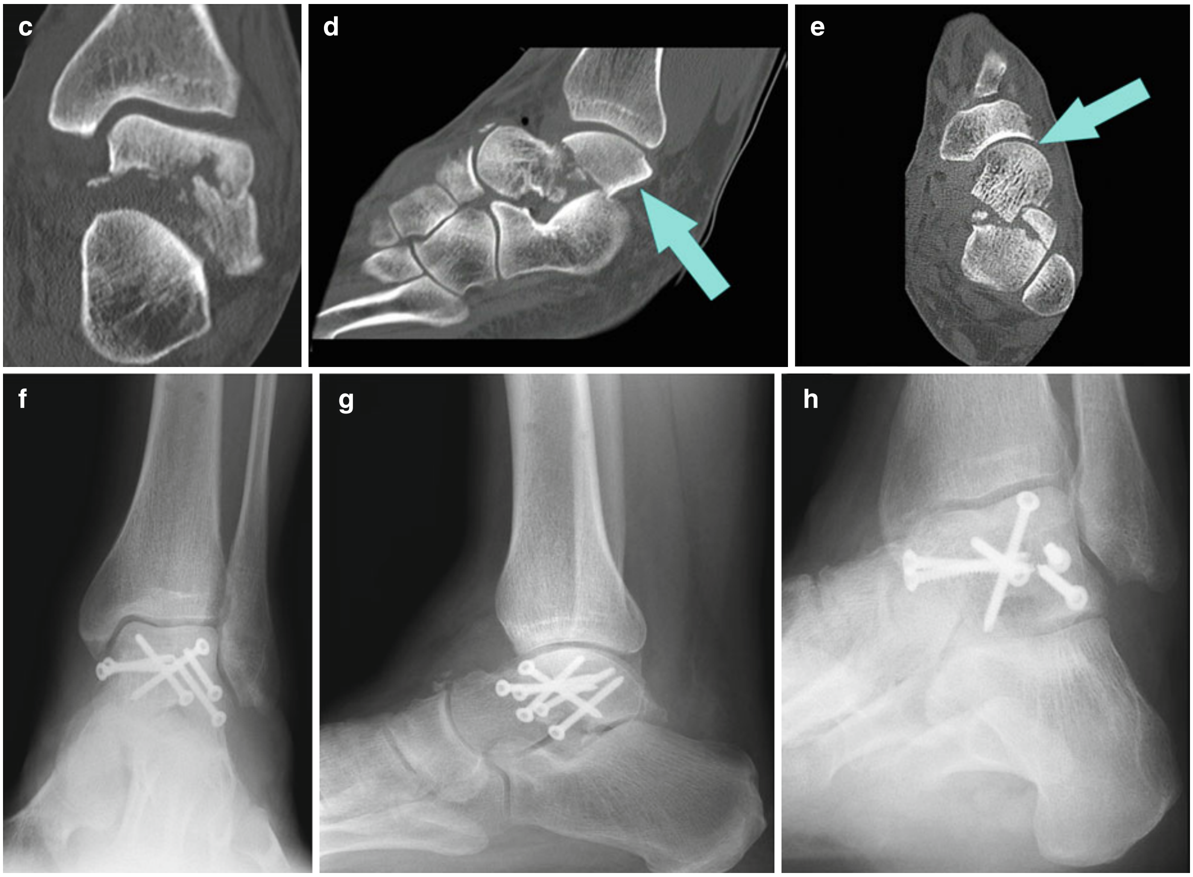

Fig. 28.7 (continued)

28.4.12.2 Open Fractures and Dislocations

General emergency principles are:

- Debridement, lavage, and decontamination
- Open reduction using the existing wound, if possible
- Definitive screw osteosynthesis, if necessary, with a second approach
- K-wire transfixation for joint dislocations
- Tibiometatarsal external fixation to allow for soft-tissue healing
- Tension-free or secondary wound closure
- Early flap coverage for large soft-tissue defects

The preservation of the talus after copious lavage is indicated even in the rare case of total talar dislocation, “Luxatio tali totalis.” Any soft-tissue insertions to the talus should be carefully preserved as they may serve as blood supply for revascularization [62].

28.4.12.3 Peripheral Talar Fractures

Talar head fractures may result from midtarsal (Chopart) fracture dislocations, therefore, additional fractures of the cuboid, navicular, or anterior calcaneal process as well as ligamentous instabilities have to be ruled out [63]. Displaced talar head fractures are reduced anatomically via an anteromedial approach. Depending on the fragment size, the fragments are fixed with 2.7- or 3.5-mm cortical screws, which are countersunk under the cartilage surface.

Fractures of the lateral process should be treated by open reduction via an Ollier approach and internal fixation with 2.0- to 2.7-mm screws. Comminuted lateral process fractures, small fragments, or old, overlooked lesions are excised [37, 64]. Posterior process fractures are reduced and internally fixed with screws via a posterior approach to avoid painful malunion or nonunion affecting the ankle and subtalar joints.

Surgical treatment for stage-III and IV osteochondral injuries according the Berndt and Harty [19] is indicated. Larger fragments >7 mm can be fixed open or arthroscopically with minifragment screws, absorbable pins, or fibrin glue [65, 66] (Fig. 28.8). Smaller fragments are excised.

Arthroscopic therapy with debridement, drilling of the subchondral bone, or microfracture and curettage is recommended for small and medium-sized lesions less than 3 cm^2 [67, 68]. Patients with extensive lesions, high functional demand, or failure after arthroscopic drilling and curettage can be treated with bone/cartilage autotransplantation (mosaicplasty, OATS = osteochondral autologous transplantation), extraction of chondrocytes from the patient, in vitro culture followed by transplantation back into the body defect that requires regeneration (ACT = autologous chondrocyte transfer; MACT = matrix associated chondrocyte transfer), or use of 3D porous materials to stimulate the in-growth of new tissue (AMIC = autologous matrix induced chondrocytogenesis) [69–72].

28.4.12.4 Subtalar Dislocations

Reduction of a subtalar dislocation should be performed emergently, because persistent malposition endangers the perfusion of the skin as well as the talar body. Most medial dislocations can be reduced under general anesthesia with a flexed knee; the plantar flexed foot is pulled distally and is then dorsiflexed and pronated, and direct digital pressure on the dislocated talar head assists the reduction. The medial dislocation is rarely complicated by incarceration of the short toe extensors, requiring an open reduction via an Ollier or anterolateral approach. A talocalcaneal transfixation with K-wires for 6 weeks is required if instability persists after closed reduction.

For lateral subtalar dislocation, an assistant holds the forefoot and the heel, while the surgeon takes the lower leg with one hand, forces the calcaneus on his/

Fig. 28.8 The patient suffered from a supination injury of his left foot. Initial X-ray analysis (**a**, **b**) suspected an osteochondral defect of the lateral talus dome (*arrow* in **a**). The preoperative CT scan showed a flake fracture stage III according to Berndt and Harty (**c**, **d**). Stress X-rays revealed a lateral tilt of 12° (**e**), whereas intraoperatively the anterior talofibular and calcaneofibular ligaments were ruptured, but the posterior talofibular ligament remained intact. A osteochondral flake measuring 0.5 × 1 cm (**f**, **g**) was found and refixed with two absorbable pins (**h**). Both ligaments could be stitched directly because of intraligamentous rupture

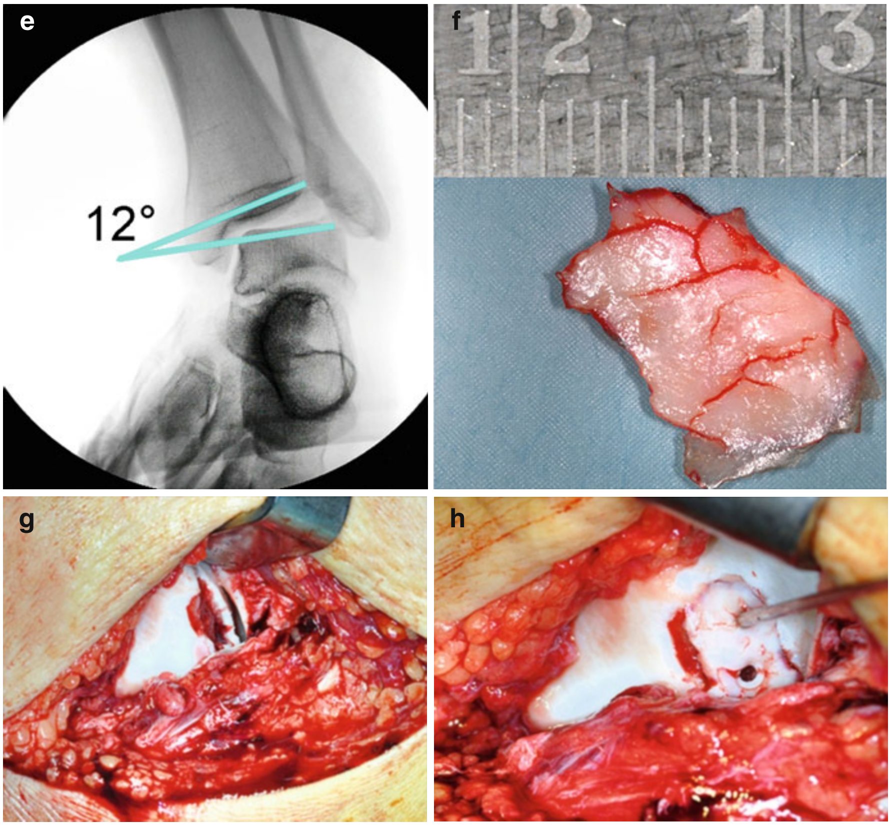

Fig. 28.8 (continued)

her knees, and manipulates the talus head with his/her other hand [4]. This dislocation is often associated with an interposition at the posterior tibial or flexor digitorum longus tendon, which requires an open reduction via an Ollier approach.

28.4.13 Postoperative Management

For optimal recovery of joint function, early functional postoperative treatment is essential with active and passive range-of-motion exercises beginning the second postoperative day, if no transfixation was performed. Weight bearing is limited to 20 kp for 8–12 weeks for central talus fractures, depending to the fracture type and radiological consolidation. Weight bearing is limited to 20 kp for 6 weeks for osteochondral fractures. Residual instability after reduction of dislocations and fracture dislocations require a temporary external or internal transfixation for 6 weeks to ensure stable ligament healing [55].

28.5 Malunion, Nonunion, and Avascular Necrosis of the Talus

Malunion and nonunions of a fractured talus are more likely after conservative than after operative treatment. The rate of avascular necrosis and post-traumatic arthritis depends mainly on the amount of fractured parts and the degree of initial dislocation, however, factors such as how anatomically the talus is rebuilt and how stably the fractured parts are fixed with screws or little plates so that early functional postoperative-treatment is possible also have an impact.

28.5.1 Definition of the Disease

Zwipp and Rammelt classification of post-traumatic malunion of the talus [73] is as follows:

- Type 1: malunion with joint incongruity
- Type 2: malunion with joint incongruity with nonunion

- Type 3: Type 1/2 with partial necrosis of the talus
- Type 4: Type 1/2 with total necrosis of the talus
- Type 5: Type 1/2 with septic necrosis of the talus

28.5.2 Epidemiology/Etiology

There is a 25–28 % incidence of post-traumatic varus malunion of the talar neck after closed reduction and plaster immobilization of Hawkins II fractures. Even mild incongruency with malunion after fractures of the talus can lead to global impairment of foot function [74].

Residual step-off and axial deviation regularly leads to post-traumatic arthritis of the ankle and subtalar joints [74]. Painful nonunion or malunion frequently occurs after peripheral talar fractures (lateral and posterior process). Impingement of the posterior tibial tendon or tarsal tunnel syndrome may be caused by bony prominences. Complete collapse of the talar body can occur as a result of complete avascular necrosis [75]. Secondary displacement of initially undisplaced talar neck fractures (Hawkins I) have been reported [47]. The incidence of delayed union or nonunion after central talar fractures is 0–10 % [40, 47, 53].

28.5.3 Diagnosis

28.5.3.1 Recommended European Standard Diagnostic Steps of Investigation

Anteroposterior, dorsoplantar, and lateral weight-bearing radiographs of both ankles and feet as well as CT scans for preoperative analysis and planning.

28.5.3.2 Additional Useful Diagnostic Procedures

MRI is useful for evaluation of the vascularization of the talus.

28.5.4 Therapy

Secondary anatomical reconstruction for type I/II/III malunions in the absence of arthritis. Arthrodesis for post-traumatic arthritis should be restricted to the affected joints avoiding further loss of function. The talonavicular joint should be spared/preserved whenever possible. Early correction may prevent arthritis of adjacent joints. Painful malunion and nonunion after peripheral talar fractures (lateral and posterior process) are treated with excision or subtalar fusion in case of severe arthritis.

28.5.5 Prognosis

Anatomical reconstruction of type I–III malunions leads to favorable results in selected patients [76]. Fusion of the ankle/subtalar joint produces predictable pain relief and functional recovery in cases of painful arthritis [77] (Figs. 28.9 and 28.10). Loss of the talar body has a poor prognosis.

28.5.6 Exemplary Surgical Procedures

28.5.6.1 Malunion/Joint Displacement

Anatomical reconstruction via corrective osteotomy preserving all three joints, if there is no arthritis, infection or total avascular necrosis with collapse of the talar dome [75]. Bilateral approach using anteromedial plus Ollier approach, followed by atraumatic handling of soft tissues is recommended. After reconstruction, the osteotomy in the previous fracture line is fixed with screws. Bony defects can be bone grafted.

28.5.6.2 Nonunion with Joint Displacement

A bilateral approach is used. Nonunion should be resected completely and the malalignment as well as the joint surfaces must be corrected. The perfusion of the adjacent bone can be enhanced by drilling. The defect from resection of the nonunion is filled with cancellous bone or corticocancellous block grafting with osteosynthesis using two or three compression screws.

28.5.6.3 Malposition and Avascular Necrosis

This step begins with debridement of necrotic bone and correction of the axial deviation, followed by filling of the defect with cancellous bone or corticocancellous block graft. With osteonecrosis and collapse of the talar body, an additional subtalar or ankle arthrodesis is required after grafting the talar body (Fig. 28.9). With partial avascular necrosis, anatomic reconstruction and screw fixation is possible.

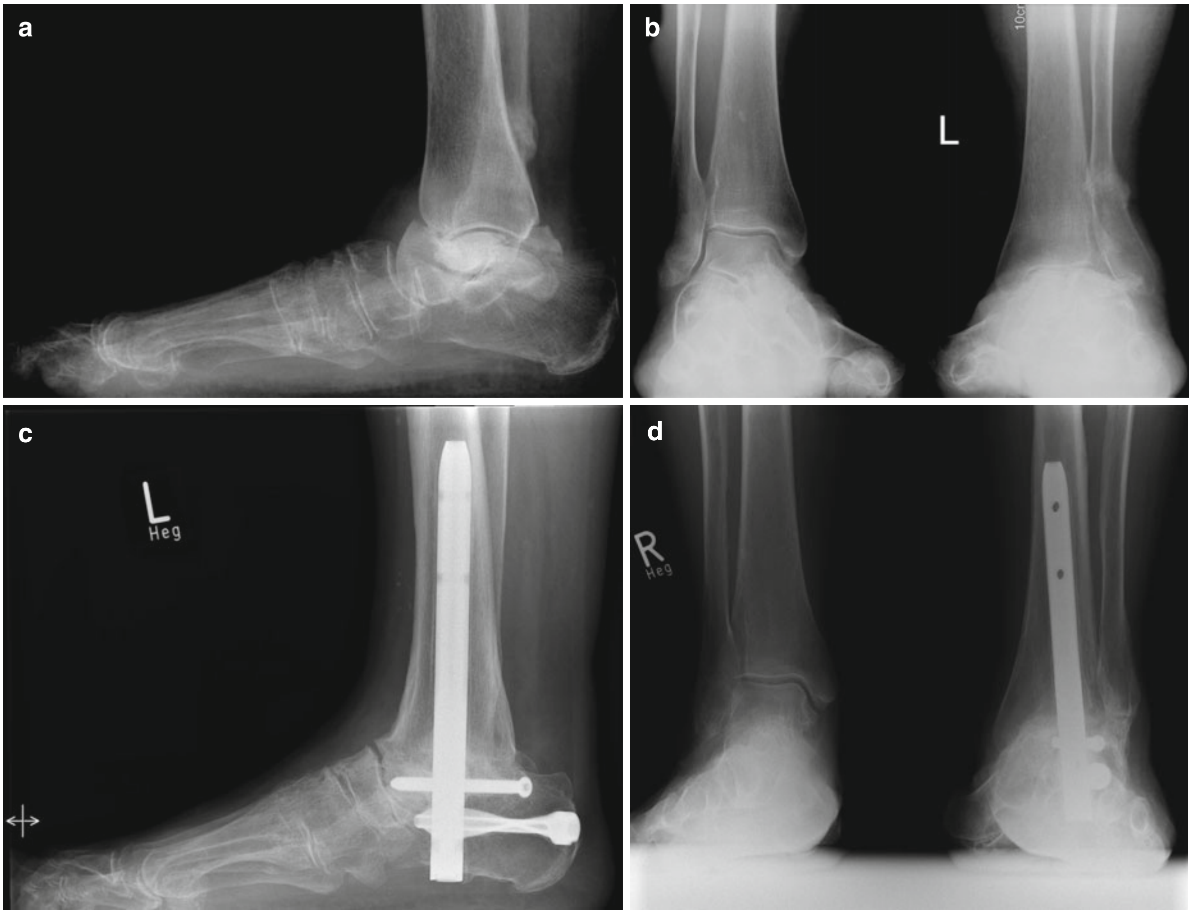

Fig. 28.9 Total avascular necrosis (ANV) with collapse of the talar body in a 72-year-old, active woman 6 months after a talar body fracture (**a**). The loss of height resulted in a fibular stress fracture (**b**). Treatment consisted of necrectomy, bone grafting, and retrograde intramedullary nailing with an interlocking distal femur nail. The 2-years follow up shows a consolidated hindfoot fusion (**c**, **d**). The patient is free of pain

Complete avascular necrosis of the talus requires complete excision of the necrotic corpus, preserving the anteromedial facet joint and the talonavicular joint, if possible. Tibiocalcaneal arthrodesis with a sliding bone block from the anterior distal tibia edge, so-called Blair fusion, is needed for complete loss of the talar body [78]. Tibiocalcaneal fusion with retrograde nailing [79] has better biomechanical stability but leads to unphysiological loading of the distal tibia with an increased risk for stress fractures [80].

28.5.6.4 Malposition and Septic Necrosis

Treatment includes radical debridement, defect filling with antibiotic beads (e.g., gentamycin), tibiometatarsal transfixation with an fixateur externe, and planned revisions to eradicate the infection. After eradicating the infection, the defect is filled with bone graft. Loss of length after talectomy is prevented by anteromedial translation of the calcaneus [81]. Secondary lengthening procedures are possible.

28.6 Fractures of the Calcaneus

The calcaneus (calx = heel) is not only the largest bone of the tarsus the supporter of the talus, especially with the sustentaculum tali, but it is also the main part of the lever arm to which the strongest tendon of the human body, the tendon of the triceps surae muscle, is attached. This tendon is well known by the name of the

Fig. 28.10 Preoperative dorsoplantar (**a**), anteroposterior (**b**), Saltzman (**c**), and lateral (**d**) weightbearing views show a severe ankle arthritis stage III according to Bargon in comparison to the contralateral side (**b**, **e**). Four-screw arthrodesis of the ankle joint via anterior approach was performed. Postoperative anteroposterior (**f**) and lateral (**g**) views show a beginning bony fusion of the ankle joint 2 months later

brave but wounded Greek hero Achilles. Fractures of the calcaneus occur five times more often than talar fractures, and the thin soft tissue envelope is always critically involved.

28.6.1 Anatomy

The calcaneus is the largest bone of the foot. The calcaneus makes up the posterior part of the longitudinal foot arch and the lateral foot column. The calcaneus has four bony processes: (1) sustentaculum tali, (2) tuber calcanei, (3) anterior calcaneal process, and (4) peroneal trochlea. Blood supply is from the lateral and medial calcaneal arteries, which originate from the posterior tibial artery.

The calcaneus acts as a strong lever arm during walking, standing, and crouching. The Achilles tendon, the largest tendon of the human body, is attached to it, transmitting the force of the triceps surae muscle to the foot. The Achilles tendon is attached to the posterosuperior part of the calcaneal tuberosity.

The inferior part, which can be further divided into a medial and a lateral process, anchors the plantar aponeurosis, the flexor retinaculum, and intrinsic foot muscles. The anterior process serves as a strong buttress leading to the navicular and cuboid bones, which are attached to it via strong bifurcate and dorsal calcaneocuboidal ligaments. Three of the four joint surfaces are located on the superior aspect of the calcaneus, representing the facets of the subtalar joint complex that articulates with the talus. With the inferior surface of the talus, the calcaneus forms the tarsal canal medially and the sinus tarsi at its widened lateral portion.

28.6.2 Physiology/Pathophysiology

The inferior aspect of the tuberosity is the strong posterior point of weight bearing. The cortical bone of the calcaneus is especially thin at the lateral side of the calcaneus, which leads to lateral bulging and lateral wall blowout in the majority of calcaneal fractures. Gissane's crucial angle has a normal value of 120–145° (Fig. 28.11). The tuberosity joint angle described by Böhler varies between 25° and 40° (Fig. 28.11).

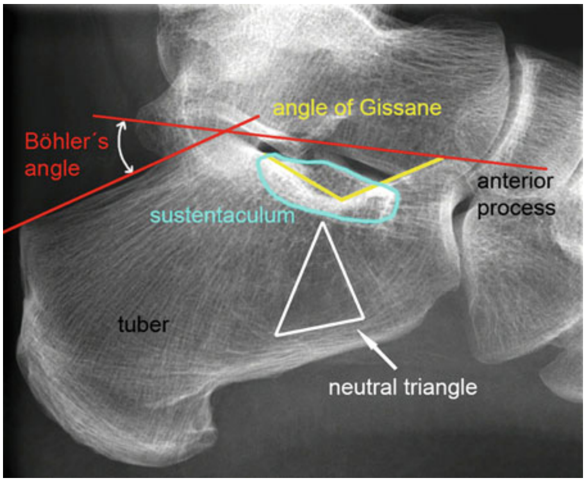

Fig. 28.11 Radiological anatomy of the calcaneus in the lateral view

The biconcave, saddle-shaped calcaneocuboid joint surface is important for the range of motion in the Chopart joint as well as for the static function of the lateral buttress of the foot. The subtalar joint complex allows considerable inversion/eversion movement of the hindfoot and adaptation of the foot on uneven ground.

28.6.3 Organ-Related Disease: Definition of the Disease

A 12-point fracture scale that reflects the number of fragments (2–5 points), involved joint surfaces (0–3 points) as well as the extent of soft tissue trauma and accompanying fractures of neighboring bones (additional 4 points), introduced by Zwipp, has a predictive value of 86 % [4] (Fig. 28.12). The most widely used classification is that of Sanders [83], which is based on the number of fracture lines at the posterior facet, seen in the coronal plane on CT scans (Fig. 28.13):

- Sanders I: undisplaced articular fragments
- Sanders II: one fracture line and two articular fragments
- Sanders III: two fracture lines and three articular fragments
- Sanders IV: three or more fracture lines with four or more articular fragments

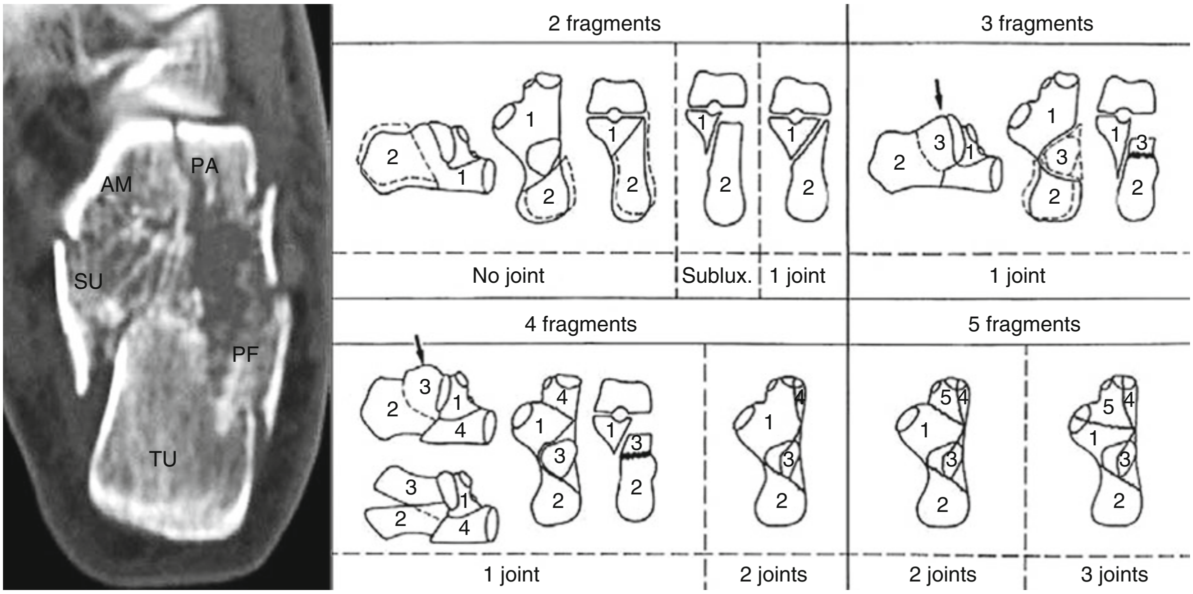

Fig. 28.12 Classification according to Zwipp [82]. The prognosis depends on the number of main fragments and affected joints (From Zwipp [4]). (1) *SU* sustentacular fragment, (2) *TU* tuberosity, (3) *PF* posterior facet, (4) *PA* anterior process fragment, (5) *AF* anteromedial facet

Laterally situated fracture lines are encoded with the letter A, intermediate with B, and medial ones with the letter C.

The AO/ICI classification of fractures is a comprehensive fracture classification for the foot and can also be used for calcaneal fractures. This classification differentiates between extra-articular fractures (type A), intra-articular fractures (type B), and fracture dislocations (type C) and allows coding for the number of joints involved as well as subgroups for type of tissue injured, kind of injury, and extent of displacement or dislocation [16].

28.6.4 Epidemiology/Etiology

Fractures of the calcaneus are the most frequent fractures of the hindfoot, with an incidence of 1–2 % [4]. Men are afflicted four to five times as often as women. The common age group affected is between 20 and 30 years of age. Many occur in male industrial workers. Fractures are typically produced by an axial force. The majority result from a fall from a height or from motor vehicle accidents.

28.6.5 Symptoms

Typical symptoms are swelling of the hindfoot and ankle region, hematoma as well as pain below the malleoli, difficulty in weight bearing on the affected leg, and reduced ability to pronate and supinate the foot. Lateral cortical bulging and valgus deformity of the hindfoot are also often seen.

28.6.6 Pathology

Important factors affecting fracture morphology are the amount and direction of the impacting force, the foot position during the accident, the muscular tone of the calf and plantar muscles, and the mineral content of the bone. There are five main fragments, namely the tuberosity, the sustentaculum, the posterior facet, the anterior process, and the anteromedial facet, with a maximum of three affected joint surfaces [4] (Fig. 28.12).

The typical primary fracture line [85] begins at the angle of Gissane, which is a result of the eccentrically directed vertical axial force and the diverging

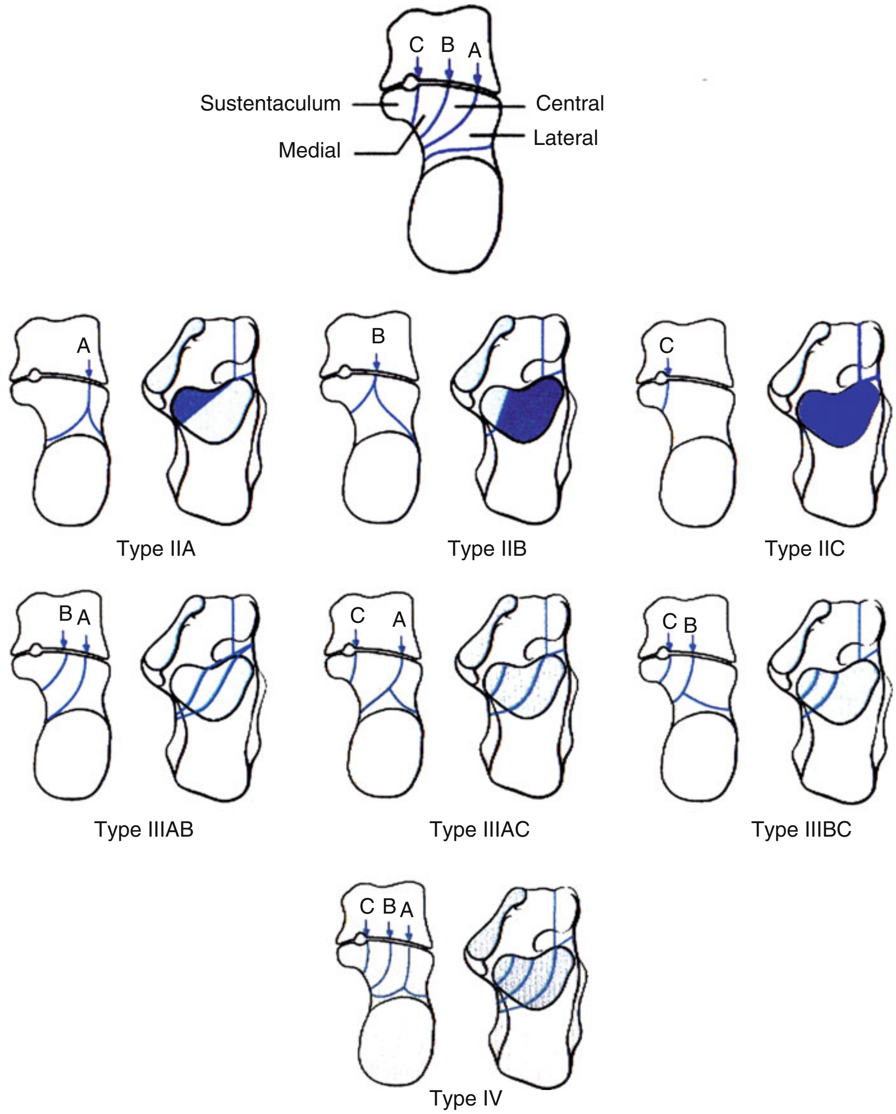

Fig. 28.13 Sanders classification of intra-articular calcaneal fractures (From Sanders et al. [84])

longitudinal axes of the talus and the calcaneus forming an angle of about 25–30°. Results of this sagittal plane fracture are two main fragments: a superomedial (sustentacular) and a posterolateral (tuberosity and body) fragment. The foot position at the time of impact determines the course of this primary fracture.

With the hindfoot in eversion, the fracture line lies more laterally, creating a large superomedial fragment. With the hindfoot in inversion, the fracture line lies more medially, sometimes producing isolated fractures of the sustentaculum. The fracture mechanism consistently results in a lateral wall blowout ("bulging"), leading to impingement of the soft tissues around the fibular tip and the peroneal tendons.

If the energy of the impact is not completely exhausted, secondary fracture lines develop. These begin at the posterior aspect of the subtalar joint [85]. In joint depression-type fractures, the secondary fracture line runs downward posterior to the impacted posterior facet.

In tongue-type fractures, the secondary fracture line extends longitudinally into the tuberosity, probably owing to a strong active pull of the Achilles tendon [4], resulting in a complex deformity of the hindfoot, neutralizing and sometimes even reversing the tuberosity joint angle (Fig. 28.14). Additional secondary fracture lines may extend anteriorly and into the sustentacular fragment or the calcaneocuboid joint, forming anterior process and anteromedial facet fragments.

Special fracture types are avulsions of the bifurcate ligament at the superomedial tip of the anterior process by forced inversion of the foot (Fig. 28.15) and fractures of the superior aspect of the tuberosity produced by a violent contraction of the gastrocnemius-soleus muscle complex, resulting in an avulsion of the Achilles tendon insertion. Beavis and colleagues [86] proposed a classification for describing calcaneal tuberosity avulsion fractures: type I is a sleeve fracture, type II a beak fracture, and type II is an infrabursal avulsion fracture from the middle of the tuberosity. Direct lateral impaction result in extra-articular fractures of the tuberosity. Medial force may generate isolated fractures of the medial tubercle of the tuberosity. Isolated compression fractures of the anterior process may occur as a component of fracture-dislocations at the midtarsal (Chopart's) joint.

28.6.7 Diagnosis

28.6.7.1 Recommended European Standard Diagnostic Steps of Investigation

- Inspection: swelling and hematoma of the hindfoot and ankle region
- Palpation: tenderness over the heel
- Difficulty in weight bearing on the affected leg
- Reduced ability to pronate and supinate the foot
- Assessment of the soft-tissue status

An acute compartment syndrome, which occurs in 10 %, can be excluded with serial clinical examination and/or repeated measurement of the compartment pressure. Standard radiographs include axial and lateral views of the calcaneus supplemented by a dorsoplantar view of the foot. If an intra-articular fracture is suspected, axial and coronal CT scanning has to be carried out. This allows a three-dimensional analysis of fracture morphology, involvement of the joint facets, and precise surgical planning. The modern classification systems of calcaneus fractures are based on CT scans.

28.6.7.2 Additional Useful Diagnostic Procedures

Lateral radiographs of the contralateral uninjured side are recommended for exact assessment of reduction [4] if surgery is indicated, since there can be individual differences in morphology, especially Böhler's angle. Anteroposterior films of the ankle joint are obtained to see the amount of fibulocalcaneal abutment. Oblique views of the subtalar joint, the so-called Brodén view, can help to demonstrate the extent of subtalar joint involvement.

28.6.8 Therapy

28.6.8.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

Conservative therapy is indicated for extra-articular fractures without significant malposition of the hindfoot (varus <5°, valgus <10°, shortening or enlargement <20 % of the other side), undisplaced intra-articular fractures (Sanders type I), as well as when there are contraindications to surgery [16]. The patient is restricted to bed rest for 3–4 days. The injured limb is elevated and ice is applied to the foot. To reduce soft-tissue swelling, the use of nonsteroidal antiinflammatory drugs may be helpful (e.g., ibuprofen 3 × 600 mg p.o./d in combination with pantozole 40 mg p.o./d). Encourage emptying of the venous plexus with venous pump training. Administering of low-molecular-weight heparin is mandatory.

The patient is mobilized with partial weight bearing of the injured leg for 3–6 weeks. Full weight bearing can be allowed after 6–12 weeks, depending on the bone quality and fracture anatomy. The goal is early mobilization of the patient. Physical therapy is directed towards regaining full range of motion in the ankle, subtalar, and Chopart joints early. Special footwear, for example, with a flexible arthrodesis boot (Variostabil), and full weight bearing may be allowed after 8–10 days.

General contraindications to surgery are severe neurovascular insufficiency, poorly controlled insulin-dependent diabetes mellitus, poor compliance, and severe systemic disorders with a poor overall prognosis or immune deficiency. Relative contraindications include age over 65 years, depending on the patient's overall condition and functional demand. Local contraindication to surgery is critical soft tissue damage with high infection risk, such as, significant blistering, skin necrosis, ulceration, and advanced arterial or venous insufficiency.

Fig. 28.14 A calcaneal tongue type fracture, type II according to Beavis classification, is shown in the anteroposterior (**a**), lateral (**b**), and hindfoot (**c**) views as well as in the axial (**d**) and lateral (**e**) CT scans of a 22-year-old patient after a motorcycle injury. Closed reduction and percutaneous screw osteosynthesis has been performed (**f**, **g**)

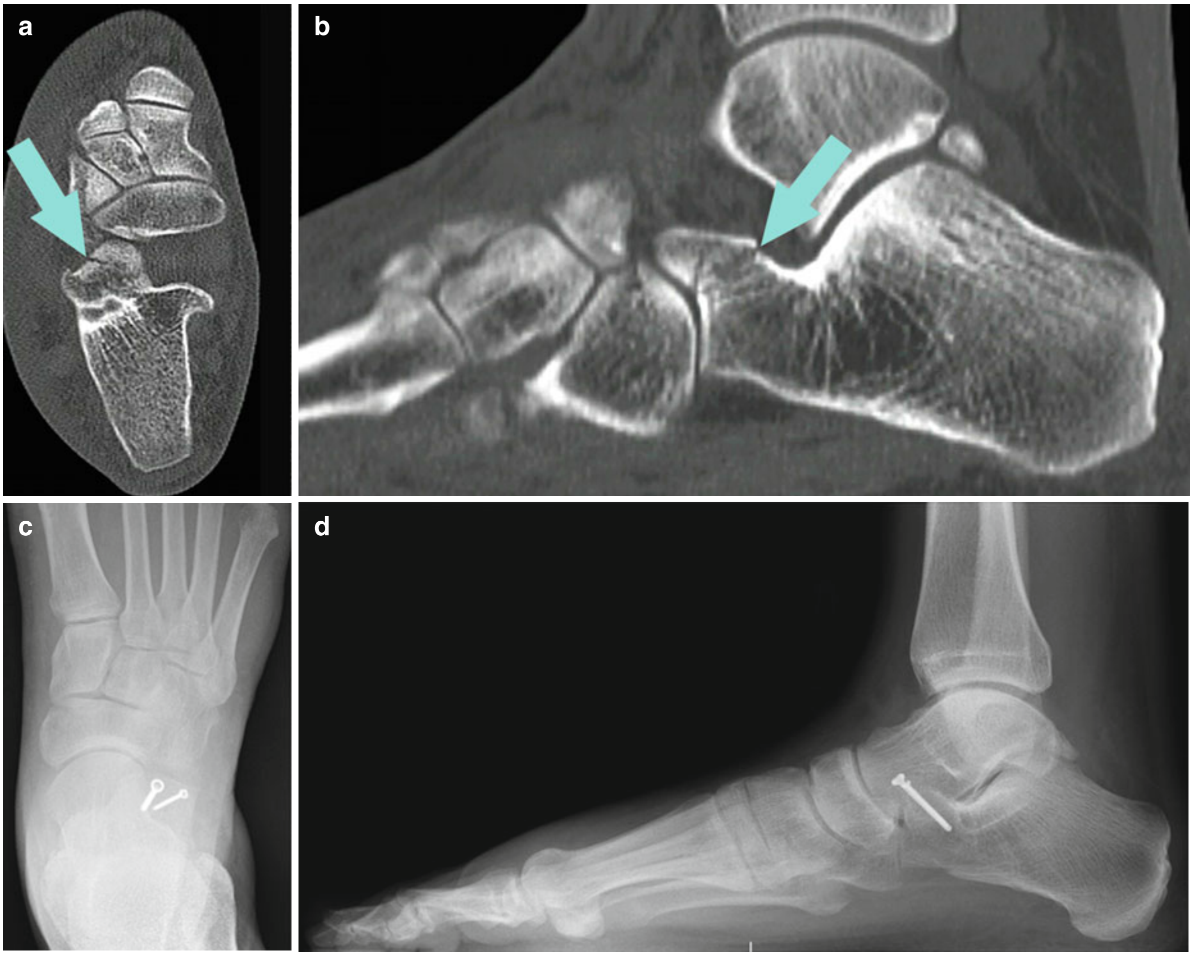

Fig. 28.15 Preoperative axial (**a**) and lateral (**b**) CT scans of an anterior process fracture (*arrow* in **a** and **b**) of the calcaneus are shown, which has been open reduced and fixed with two screws (**c**, **d**)

28.6.9 Surgery

28.6.9.1 Recommended European Standard Surgical Procedures

All intra-articular fractures with joint displacement of more than 1 mm and extra-articular fractures with a hindfoot varus of more than 5°, hindfoot valgus of more than 10°, or considerable flattening, broadening, or shortening of the hindfoot should be treated operatively. Soft-tissue condition and associated injuries are crucial for timing of surgery. Emergency procedures are needed for open fractures and closed fractures with compartment syndrome or severe compromise of the soft tissues by fracture fragments.

Open fractures require initial debridement of the wound, which is typically situated medially, temporary closure with skin substitutes, minimally invasive fracture reduction and K-wire fixation supplemented by an external fixator. After 48–72 h, a second look with debridement is carried out and the type of soft-tissue coverage required is determined. A standard internal fixation is performed after soft-tissue consolidation, mostly within 10–12 days.

Monotraumatized patients with compartment syndrome should undergo release of the hematoma followed by a standard osteosynthesis. The majority of calcaneal fractures are accompanied by considerable soft-tissue compromise, representing Tscherne grade II closed soft-tissue damage [87].

Delayed osteosynthesis is preferred after the swelling has markedly decreased, usually within 10 days. Open reduction and internal fixation of intra-articular calcaneal fractures aims to restore the anatomical shape of the calcaneus, anatomically reconstruct all affected joint surfaces, and achieve stable osteosynthesis without joint transfixation so as to allow early active and passive movement (Fig. 28.16).

28.6.9.2 Additional Useful Surgical Procedures

In polytraumatized patients with compartment syndrome of the foot, a classic dorsomedian dermatofasciotomy is carried out, releasing the skin, dorsal fascia, and distal extensor retinaculum, followed by external fixation [4]. The deep calcaneal compartment is released by a separate hindfoot incision similar to that used for a plantar fascia release [88].

Because of the critical soft-tissue condition, minimally invasive treatment options such as fluoroscopic and arthroscopically assisted fixation for selected fracture patterns have gained increased attention in recent years [89, 90]. Limited approaches and percutaneous osteosynthesis are employed with critical soft-tissue conditions, in polytraumatized patients, and in selected patients with contraindications to open surgery [91].

28.6.10 Prognosis

Osteoarthritis is evident in 90 % of conservatively treated Sanders type IV fractures of the calcaneus [92]. Timing of surgery and careful treatment of associated soft-tissue injuries is as important as proper fracture reduction. Use of local and free microsurgical soft-tissue coverage is useful in the treatment of higher-degree open fractures of the calcaneus. Surgery is ideally performed within the first 3 weeks of injury prior to early fracture consolidation but must be delayed until the associated soft tissue swelling has adequately dissipated, as indicated by a positive wrinkle test [83, 93]). Surgery, which is delayed beyond 3 weeks after injury, especially in cases with total hindfoot collapse, can lead to a difficult reduction and higher complication rates due to shrinking of the skin and soft-tissue contracture.

28.6.11 Complications

Calcaneal fractures are frequently overlooked in polytrauma patients, especially isolated sustentacular fractures. Continuous assessment of the soft-tissue status is important, since blister formation may develop within a few hours and, with severe fragment pressure from within, skin necrosis could occur. These factors delay surgical fixation and may provoke soft-tissue breakdown or infection, further worsening the final outcome. With severe soft-tissue swelling a compartment syndrome has to be ruled out. The deep calcaneal compartment contains the quadratus plantae muscle and the lateral plantar nerve [94].

There is an incidence up to 25 % of superficial aseptic wound edge necrosis [93, 95–99]. A 1.3–12 % incidence of deep soft-tissue and bone infection after open surgery has been reported [95, 98–100].

Therapy includes radical debridement, removal of implants, insertion of antibiotic beads, tibiometatarsal external fixation, and systemic antibiotic therapy [101].

28.6.12 Exemplary Surgical Procedures

The extended lateral approach represents the standard approach for displaced intra-articular fractures of the calcaneus [102, 103]. A multitude of surgical approaches exist, including lateral, medial, and combined medial-lateral approaches. A modified medial approach, the so-called "sustentacular approach" [4], can be used for isolated sustentacular fractures or as a supplement to the extended lateral approach when there is fragmentation of the medial facet. A combined medial–lateral approach may be beneficial in rare cases of destruction of the medial joint facet in comminuted fractures. This was proposed by Stephenson [104]. Complications are minimized by careful soft-tissue handling. Fixation can be achieved with a lateral plate that is contoured and fixed to the calcaneus with 3.5-mm cortical or cancellous screws. For more unstable fracture patterns, an anatomic stainless steel plate with interlocking screws is recommended [103]. Two of the screws should be directed into the sustentaculum tali, two or three into the tuberosity, and two into the anterior process close to the calcaneocuboid joint.

One or two additional screws may be placed outside the plate in order to obtain ideal positioning into the sustentaculum tali or for a severely displaced anterior process, anterior facet, or tongue fragment. Correct anatomical restoration, joint congruency, and extra-articular position of the screws are documented by

Fig. 28.16 A young patient suffered from a 3 joint/5 fragment calcaneal fracture according to Zwipp, type IV according to Sanders classification after a fall from 3 m height. The antero-posterior (**a**), oblique (**b**), and lateral (**c**) X-rays and the antero-posterior (**d**), axial (**e**), and lateral (**f**) preoperative CT scans show a comminuted calcaneal fracture, affecting the subtalar, calcaneonavicular, and calcaneocuboidal joints. Open reduction via an extended lateral approach and internal fixation with a locking plate (winkelstabile Calcaneusplatte) was performed. Postoperative Broden view shows a reconstructed subtalar joint surface (**g**), an alignment of the hindfoot axis (**h**), and a reconstructed calcaneal height in the lateral view (**i**)

standard radiographs: a dorsoplantar view of the foot, lateral and axial views of the hindfoot, including a 20° Broden view.

After careful hemostasis, the skin is closed in layers. With considerable bleeding from the cancellous bone, a collagen sponge may be introduced epiperiosteally. A sterile compression dressing is applied to the foot and postoperatively a below-the-knee split plaster cast is applied to the injured leg.

28.6.12.1 Medial Approach

The patient is placed on the operating table in a supine position with a tourniquet on the thigh of the injured leg. A horizontal incision or a lazy-S incision in line with the skin creases, about 8–10 cm, is made exactly halfway between the tip of the medial malleolus and the sole. The subcutaneous plane and fascia are dissected. The next step is careful dissection and mobilization of the neurovascular bundle, which is marked and held away with a Penrose drain. The abductor hallucis longus muscle is retracted downward, whereas the flexor hallucis longus tendon is identified and left in place. The sustentacular fragment of the calcaneus is now visualized with preparation down to the periosteum.

A cancellous 6.5-mm Schwanz screw with a T-handle is introduced into the tuberosity via a stab incision. The tuberosity fragment can now be reduced by axial pull, away from the sustentacular fragment and the anterior process. If correct anatomical reconstruction of the medial wall is achieved, the reduction is fixed temporarily with 1.6–2.0 mm K-wires. Temporary transfixation of the joint may be necessary. Definitive fixation is achieved with a small anti-glide "cervical" H-plate and four 3.5-mm cortical screws, of which one should run into the anterior process fragment and two into the tuberosity fragment. Contour the H-plate according to the individual contour of the medial wall of the calcaneus to prevent any gliding of the fragments when tightening the screws.

A classical medial "McReynolds" [105] and a direct lateral approach are required for the calcaneal fracture-dislocation with lateral and proximal translation of the tuberosity fragment [103].

28.6.12.2 Extended Lateral Approach

This is the standard approach that is most useful with displaced intra-articular calcaneus fractures that involve the posterior facet, which is fractured in 96 % of cases. The patient is placed on a radiolucent operating table in a lateral decubitus position on the noninjured side. Alternatively, the prone position is used. A tourniquet (200–300 mmHg) is placed on the thigh of the injured leg, the leg is draped free, and a sterile tape is applied to the toes. The tourniquet is used only for joint reconstruction in the absence of an additional acute compartment syndrome.

Skin incision is boomerang-shaped over the lateral aspect of the heel, running between the lateral malleolus and the posterior and inferior borders of the heel, respectively. The tip of the lateral malleolus and the fifth metatarsal base serve as landmarks for the incision. The subcutaneous layer is dissected in a strict vertical fashion down to bone. Care has to be taken to preserve the sural nerve as well as the lesser saphenous vein in the proximal incision. When extending the subcutaneous dissection distally to visualize the calcaneocuboid joint, the peroneal tendons are identified and mobilized within their sheaths, in order to prevent postoperative adhesions. They are gently held back with a blunt retractor. The calcaneus is progressively exposed epiperiosteally until the subtalar joint becomes visible. The distal retinaculum of the peroneal tendons and the fibulocalcaneal ligament are detached subperiosteally. A full-thickness cutaneous flap is developed, which can be retracted temporarily with K-wires introduced into the lateral process of the talus and the cuboid. Alternatively, sutures may be used. Use of sharp distractors is to be avoided.

When all fracture fragments are identified, the tuberosity fragment is mobilized with the Westhues maneuver. A 6.5-mm cancellous Schanz screw with a T-handle is introduced into the tuberosity after a stab incision. Under direct visualization of the subtalar joint, the handle is moved downward in order to bring the tuberosity fragment back to its correct position. At the same time, varus or valgus malalignment is corrected. The posterior facet is now reduced in a stepwise fashion from medial to lateral. Should the medial portion of the posterior facet be tilted laterally it must be reduced congruently to the inferior joint surface of the talus first and fixed with a 2.0 K-wire introduced from plantar into the talus. The depressed lateral portions of the posterior facet are elevated and fixed with 2.0 K-wires to the sustentaculum. If an intermediate fragment is present, the K-wires are drilled through the medial wall and pulled back to the lateral edge of this fragment. Then the lateral fragment is reduced onto the intermediate fragment. K-wires are drilled back to emerge laterally.

The K-wires are introduced 5 mm below the joint surface and are directed 10° superiorly towards the talus and 15° anteriorly towards the midfoot. The resulting articular block is then fixed to the initially mobilized tuberosity fragment. The whole posterior fragment can now be brought into alignment with the anterior process fragment to reconstruct the crucial angle. With extremely unstable fractures, temporary fixation is extended to the talus and cuboid.

Should a fifth fragment be present, the so-called anterior facet fragment, the calcaneocuboid joint has to be reduced congruently and the fragment is fixed with two additional K-wires. Reduction is confirmed by fluoroscopy, including oblique views into the subtalar joint space corresponding to the Broden views. The amount of correction of the tuberosity joint angle and varus/valgus deformity is confirmed by fluoroscopy. The quality of reduction of the crucial posterior joint facet can be confirmed by open subtalar arthoscopy (2.3 mm/30° arthroscope) after K-wire fixation, to evaluate the areas inaccessible to the eye.

If an intra-articular step is found, the position of the posterior facet should be corrected immediately. After joint reduction, the tourniquet is released. Internal fixation is completed with the use of an anatomically shaped plate affixed to the restored lateral wall of the calcaneus (Fig. 28.16).

Screw osteosynthesis is generally preferred in isolated fractures of the calcaneus instead of K-wire transfixation, because it provides sufficient stability and allows for early mobilization (Fig. 28.16). The exact number and position of screws depend on the individual fracture pattern. When the duration of surgery must be kept to a minimum in polytraumatized patients, K-wires are used instead of screws and are supplemented by tibiometatarsal transfixation or three-point distraction (calcaneal tuberosity, talar head and navicular or medial cuneiform) with an external fixator. If no definitive fixation is done, K-wires and external fixation devices are removed after 10–12 weeks.

28.6.12.3 Sustentacular Approach

This approach is recommended in isolated sustentacular fractures and as a supplement to the extended lateral approach in complex intra-articular fractures with fragmentation of the medial facet. The patient is placed on the operating table in a supine position. A tourniquet is placed on the thigh of the injured leg. Incision is made longitudinally about 3 cm long parallel to the sole of the foot, 1–2 cm distal and anteriorly to the tip of the medial malleolus directly over the palpable sustentaculum. The posterior tibial neurovascular bundle is identified by nearby tendons and left in place. The sustentaculum is also identified. The medial facet is reduced to the corresponding facet of the talus and two long (about 50–60 mm) 3.5-mm compression screws are introduced into the sustentaculum tali along its axis into the main tuberosity fragment.

28.6.12.4 Possible Complications of the Surgical Procedure

Deep soft-tissue and bone infection occurs in 1.3–7 % [91, 95]. In such cases, debridement and cultures have to be done until wound swabs are negative. If infection persists, the calcaneal plate has to be removed and replaced by screw osteosynthesis. Antibiotic beads (e.g., gentamycin) are inserted temporarily.

If chronic post-traumatic osteomyelitis develops despite all measures listed above, subtotal or total calcanectomy is inevitable. If soft-tissue coverage cannot be achieved even after management with synthetic skin substitutes or continuous suction, free flaps have to be considered in order to control infection and to avoid a protracted postoperative course [106].

Nonunion is very rare after stable internal fixation and can be treated with bone grafting and fixation using 6.5-mm cancellous screws. A dual approach is associated with an increased incidence of wound edge necrosis.

28.6.13 Postoperative Management

The goal is early mobilization of the patient. Physical therapy is directed towards early full range of motion in the ankle, subtalar, and Chopart joints. The injured foot is placed postoperatively in a split non-weight-bearing below-the-knee plaster cast for 8–10 days. The patient is told to press the sole of the injured foot against the plaster cast about ten times an hour in order to empty the venous plexus of the foot and reduce swelling.

Continuous passive motion of the ankle and subtalar joint is begun the first postoperative day. Physical therapy begins with active and passive, pain-restricted range-of-motion exercises in the ankle and subtalar joints on the second postoperative day. The desired motion is best achieved by scribing a circle with the great toe. Mobilization of the foot and ankle is supplemented by isotonic and isometric exercises of the affected leg, including proprioceptive training and neuromuscular facilitation. The patient is mobilized on crutches with partial weight bearing of the injured leg on the third to fifth postoperative day.

Suture material is removed after 8–10 days and the patient is mobilized in a custom shoe. Weight bearing is limited to 15–20 kp for 6 weeks, but in comminuted fractures up to 12 weeks. For the entire period, the patient must undergo an extensive physical therapy program including active range-of-motion exercises, manual mobilization of the hindfoot, and lymphatic drainage. The patient should abstain from active sports and heavy loading of the injured foot for at least 4 months. The hardware can be removed after about 1 year.

28.7 Reconstruction of the Calcaneus

Malunions of the calcaneus occur more after conservative than operative treatment, nonunions and avascular necrosis more frequently after surgical procedures. Anatomical secondary repair is less often possible than in cases of talar malunions and nonunions; osteotomies for realignment and subtalar fusions are the most common procedures [107].

28.7.1 Definition of the Disease

The Zwipp and Rammelt classification of post-traumatic malunion of the calcaneus [73] is as follows:

1. Malunion
   (a) Joint incongruence
   (b) Additional varus /valgus malposition
   (c) Additional height diminution
   (d) Additional translation
   (e) Additional subluxation of the talus
2. Nonunion
3. Avascular necrosis

28.7.2 Epidemiology/Etiology

Painful malunion of the calcaneus is caused by conservative treatment of displaced intra-articular fractures or an inadequate reduction during surgical treatment. Post-traumatic subtalar arthritis is often seen after comminuted fractures or inadequate reduction of the joint surface [88]. Joint incongruency of 1–2 mm increases the pressure in the subtalar joint and risks permanent cartilage damage [108]. Malunion is common, but nonunion and avascular necrosis are rare. Nonunion of the anterior process that develops after an avulsion of the bifurcate ligament is frequently overlooked.

28.7.3 Symptoms/Features

Widespread symptoms include widening of the hindfoot caused by the lateral blow-out, impingement of the peroneal tendons, hindfoot varus and/or valgus, horizontal tilt of the talus, hindfoot shortening because of loss of calcaneal height, and abutment of the lateral malleolus against the lateral wall of the calcaneus. Dorsal tilt of the talus causes tibiotalar impingement followed by post-traumatic arthritis of the ankle.

28.7.4 Diagnosis

28.7.4.1 Recommended European Standard Diagnostic Steps of Investigation

Dorsoplantar and lateral weight-bearing views of both feet and axial view of the hindfoot, the so-called "Saltzman view," are performed [109]. Anteroposterior weight-bearing views of both ankles demonstrate the lateral impingement and talus subluxation. CT scanning is important for operative planning and diagnosing nonunion.

28.7.4.2 Additional Useful Diagnostic Procedures

MRI can help to diagnose osteonecrosis or tendinopathy.

28.7.5 Exemplary Surgical Procedures

28.7.5.1 Joint Incongruence

Painful arthritis of the subtalar joint is treated with isolated subtalar arthrodesis [110, 111] (Fig. 28.17). A posterolateral approach can be used for removal of cartilage and sclerotic bone from the posterior facets of the talus and calcaneus. Compression arthrodesis is realized with two plantarly inserted 6.5-mm cancellous screws. If no cancellous bone is interposed, additional debridement of the medial facet is required, avoiding hindfoot valgus [4].

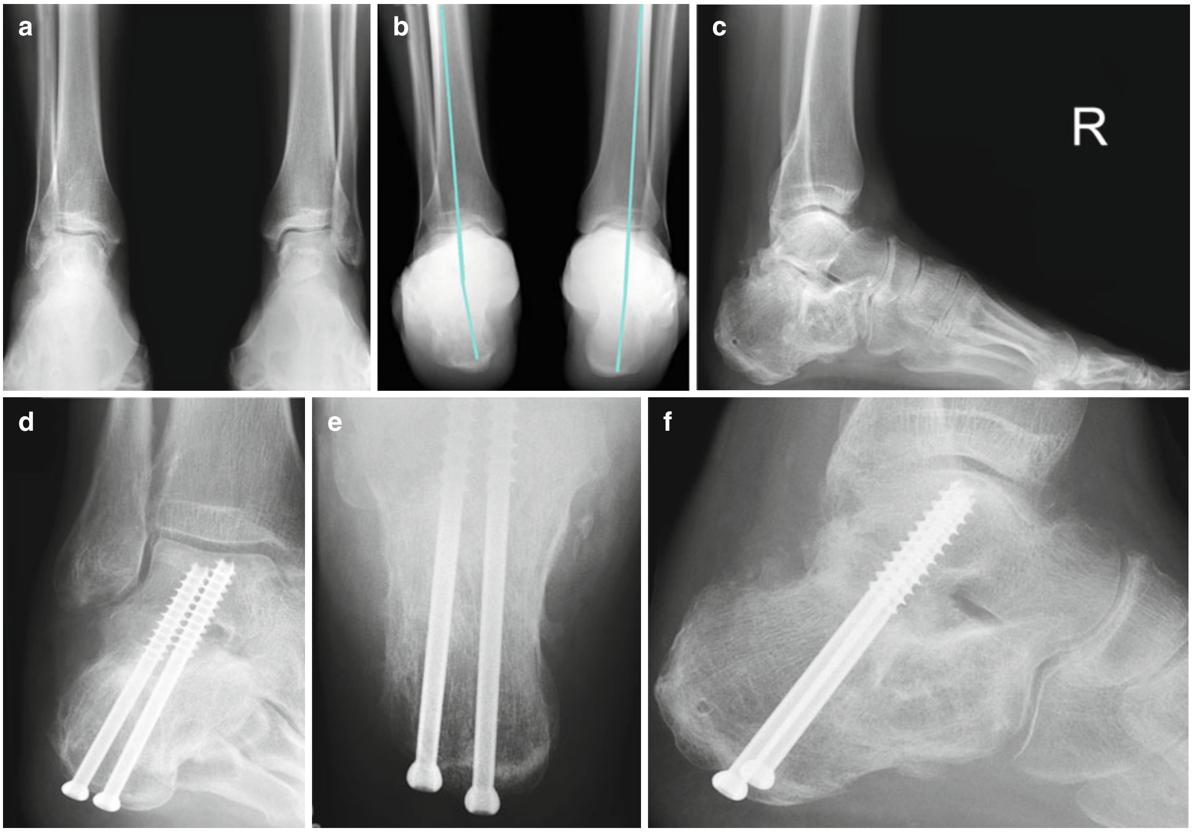

Fig. 28.17 A severe subtalar arthritis 3 years after a 3 joint/5 fragment calcaneal fracture according to Zwipp is seen in the preoperative weight bearing views (**a**–**c**). There is a 4° hindfoot valgus of the right foot and 2° of the uninjured contralateral foot (**b**). The calcaneocuboidal joint is not affected. The procedure included a reorientating subtalar arthrodesis via a posterolateral approach, interposition of tricortical bone graft from the posterior iliac crest, and fixation with two cancellous screws. Postoperative control X-rays 3 months later document a complete fusion of the subtalar joint (**d**–**f**)

Alternatively, arthroscopic minimally invasive in situ arthrodesis is possible. Follow-up is managed with a flexible arthrodesis boot or below knee case, full weight-bearing after 6–12 weeks.

28.7.5.2 Axial Malposition and Height Diminution

Varus or valgus malposition or height diminution of the calcaneus in two planes requires a prone position with a posterolateral approach according to Gallie [112]. Reorientating subtalar arthrodesis is performed with interposition of one or two tricortical bone grafts removed from posterior iliac crest [113] after complete removal of cartilage, pannus tissue, and sclerotic bone. With the shape of the tricortical bone, the varus or valgus malposition is corrected [4]. Postoperatively, patients are treated 6 weeks in a split non-weight-bearing below-the-knee plaster and 6 weeks in a flexible arthrodesis boot. Weight bearing is limited to 15–20 kp for 6 weeks [107].

28.7.5.3 Lateral Translation

A dual approach may be needed. Correction of the axial deviation is required. A corrective osteotomy through the old fracture line and subtalar arthrodesis is recommended [114, 115].

28.7.5.4 Tilt of the Talus

Preoperative 3D planning is required. A dual (medial and lateral) approach is used. The subtalar joint is mobilized and debrided. Correct positioning of the talus is controlled by an additional anteromedial approach [4], which is needed for corrective osteotomy. A double arthrodesis (ankle and subtalar joint) is reserved for cases with severe stiffness of the hindfoot and arthritis of both joints [73].

28.7.5.5 Nonunion

Nonunion is rare. First, it is completely resected, then the malposition is corrected, followed by an interposition of autologous cancellous bone and osteosynthesis with 6.5-mm compression screws. Intra-articular fragments are resected.

28.7.5.6 Necrosis

Most cases are diabetic patients with ulceration and calcaneal osteomyelitis [74]. Necrosis is rare because of the periosteal blood supply of the calcaneus. It is associated with a poor prognosis, which often ends in partial or total calcanectomy. Longtime immobilization and non-weight-bearing status are needed for healing. Functional results are moderate. Combined free costo-muscular flap shows promise in selected cases [116].

28.8 Subtalar Instability

Because of the strength of the talocalcaneal interosseous ligament compared with the weaker fibular ligaments, chronic subtalar Instability is 10 times less likely than chronic anterolateral instability of the ankle joint.

28.8.1 Organ-Related Disease: Definition of the Disease

28.8.1.1 Anterolateral Rotatory Instability of the Subtalar Joint

This is a combination of anterior translation, internal rotation, and varus tilt of the calcaneus against the talus [117].

28.8.1.2 Luxatio Pedis Sub Talo

This is a severe injury of different parts of the interosseous talo-calcaneal ligament; synonym: ligament of the canalis tarsi, as well as the internal and external talotarsal ligaments, combined instability of the subtalar and talocalcaneonavicular joints [118]. The direction of the dislocation allows differentiation between the common anteromedial and the infrequent posterolateral subtalar dislocation [4].

28.8.1.3 Luxatio Tali Totalis

This is complete enucleation of the talus, rupture of all ligamentous connections to the tibia and tarsus, combined with peripheral talus fractures, for example, fractures of the lateral or posterior process [118].

28.8.2 Epidemiology/Etiology

The cause of this injury is forced supination of the dorsiflexed foot, for example, jumping or tripping off an edge. The dislocating force continues along Hellpap's supination line proximal to distal, from the fibula via the calcaneocuboidal joint until the fifth metatarsal base [119, 120] (Fig. 28.18). Combined instability can result along that line, whereas the subtalar component could be easily overlooked, because of the low incidence [4].

Rupture of the interosseous talocalcaneal ligament (synonym: ligament of the canalis tarsi), causes anterior translation and internal rotation of the calcaneus. Additional dissection of the calcaneofibular ligament, the bifurcate ligament, and the talonavicular ligament results in a lateral tilt of the talus in the subtalar joint. Medial subtalar dislocation develops through a forced adduction with simultaneous plantarflexion and supination of the foot. The sustentaculum tali is the lever arm for the dislocation, which explains the combined appearance of sustentacular fractures and peripheral talus fractures (e.g., posterior and fibular process) [4]. Lateral dislocation results from forced abduction with simultaneous dorsiflexion and pronation of the foot. Forty-one percent of all cases are open dislocations. Pure anterior or posterior dislocations are extremely rare.

28.8.3 Symptoms

Patients with chronic subtalar instability often describe symptoms of "giving way" of the foot during activity, a history of recurrent instability and/or pain, as well as swelling and stiffness of the ankle. The symptoms are, however, often vague and it is difficult to differentiate between subtalar and tibiotalar instability. The symptoms may also include pain over the sinus tarsi or deep pain in the subtalar area. The sinus tarsi syndrome may be a presentation of subtalar instability with characteristic pain, as well as pain elicited by palpation over the sinus tarsi and pain upon forced inversion of the foot [121].

Increased internal rotation of the calcaneus is a possible finding on physical examination, and there may also be an excessive distal displacement of the calcaneus in relation to the talus compared with the

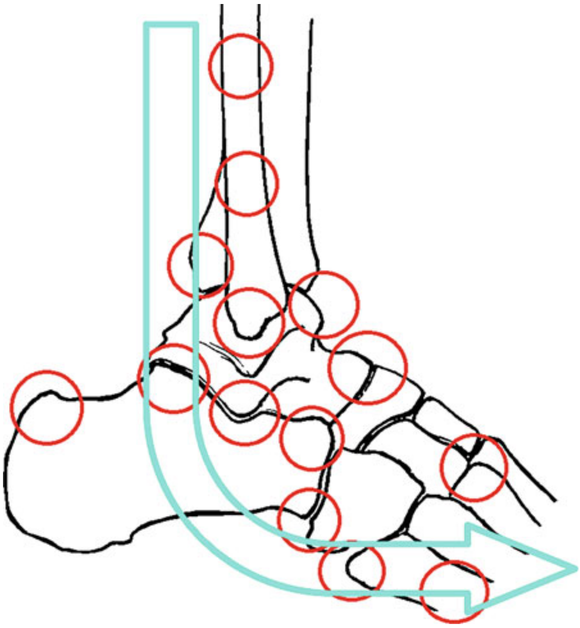

Fig. 28.18 The supination line (*green arrow*) is a fictive line along which various sprain injuries (*red circles*) can occur (From Schepers et al. [120])

unaffected side. Upon exertion of varus stress to the dorsiflexed foot, differentiation of the lateral tilt in the subtalar joint versus talar tilt at the ankle joint can be made.

Diagnostic arthroscopy under the assumption of sinus tarsi syndrome may reveal a partial lesion of the interosseous talocalcaneal ligament (synonym: ligament of the canalis tarsi) [122, 123].

28.8.4 Diagnosis

28.8.4.1 Recommended European Standard Diagnostic Steps of Investigation

Clinical examination is performed with the foot in dorsiflexion. Stress X-rays in the TELOS suspensory device with 30° internal rotation of the foot, 15 kp inversion stress on the calcaneus, and 45° craniocaudal tilted X-ray tube [124]. More than 5 mm of medial shift of the calcaneus, 5° talo-calcaneal tilt, and a lateral talo-calcaneal angle of 10° are indicative of subtalar instability [117]. Stress films of the contralateral side should be obtained for comparison. Differentiation between isolated subtalar instability and combined anterolateral instability of the ankle and subtalar joint is important.

28.8.4.2 Additional Useful Diagnostic Procedures

CT scanning for subtalar dislocations is recommended to rule out fractures of the lateral or posterior process of the talus [125].

28.8.5 Therapy

28.8.5.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

Acute subtalar instability, postreduction, can be treated with a split below-the-knee-cast for 3–5 days, and then with an ankle orthosis for further 5 weeks (e.g., Caligamed).

28.8.5.2 Additional Useful Therapeutic Options

Existing instability after closed reduction can be temporarily fixed with K-wires for 6 weeks.

28.8.6 *Surgery:* Recommended European Standard Surgical Procedures

28.8.6.1 Acute Subtalar Dislocation

Reduction of a subtalar dislocation is an emergency, because with persistent malposition the blood supply of the skin and the talus is endangered [126]. Most of the medial dislocations can be reduced with short anesthesia with a knee flexed to a right-angle. The plantar flexed foot is pulled distally and is then dorsiflexed and pronated.

Lateral Subtalar Dislocation

The assistant holds the forefoot and the heel, whereas the surgeon takes the lower leg with one hand and manipulates the talar head with his other hand [4].

Luxatio Tali Totalis

Here, immediate open reduction and dermatofasciotomy via a dorsomedial approach as well as additional lateral and medial incisions are performed to address incarcerated muscles and tendons; primary suture of ligaments is contraindicated. After reduction transfixation with K-wires and tibiometatarsal external fixation is performed for 3 weeks. Postoperative immobilization for another 3 weeks in a below-the-knee cast.Chronic Subtalar Instability

Chronic subtalar instability can be treated with a Chrisman-Snook tenodesis [127]. Anatomical reconstruction is performed with split peroneus brevis or free fascia lata graft [128]. If there is an additional anterior drawer intraoperatively, the peroneus longus tendon (as in the Watson-Jones tenodesis) is passed through a vertical V-shaped canal in the neck of the talus at the insertion of the anterior talofibular ligament. A more anatomical procedure is recommended by Pisani [129].

28.8.7 Differential Diagnosis

Common differential diagnoses are an anterolateral rotational instability of the ankle, a peroneal tendinitis, osteochondral fracture of the talus, and fracture of the lateral talar process.

28.8.8 Prognosis

Good results have been observed for the modified Elmslie procedure for isolated and combined subtalar instability in about 80 % [130].

28.8.9 Complications

For lateral dislocation, interposition of the posterior tibial and flexor digitorum longus tendon occurs frequently and requires open reduction. For medial dislocation, incarceration of the short toe extensors requires an open reduction. A 3% incidence of hematoma has been found postoperatively, and 3% experience irritation of the sural nerve. There is good prognosis for subtalar dislocation with immediate reduction, but poor prognosis for open injuries or additional fractures is reported. Prognosis for total dislocation of the talus depends on the initial soft tissue injury and point of reduction. It ranges from functionally good results to septic necrosis [4, 131, 132].

28.8.10 Exemplary Surgical Procedures

28.8.10.1 Chrisman-Snook Tenodesis (Modified by Vidal)

Surgery starts with a lateral approach for this nonanatomic reconstruction, which does not reproduce normal ankle kinematics. The peroneus brevis tendon is used, which is passed through a V-shaped canal at the insertion of the fibulocalcaneal ligament and through a drill hole from posterior to anterior at the tip of the lateral malleolus and then fixed at the tuberosity of the fifth metatarsal [133] (Fig. 28.19). This tenodesis is a modification of the Elmslie procedure for ankle instabilities, which was originally performed with a strip of fascia lata [135].

28.8.11 Postoperative Management

A below-the-knee walking cast should be used for 6 weeks. Compliant patients are allowed to wear a flexible arthrodesis boot (Variostabil).

28.9 Fractures of the Chopart Joint

The Chopart joint is anatomically known as "articulatio transversa tarsi." It connects the hindfoot with the midfoot. Together with the subtalar joint movement it allows during eversion or inversion of the calcaneus pronation and supination. This joint permits a high degree of adaptation of the foot to uneven ground. During inversion of the calcaneus, the talar head superimposes over the cuboidal facet by minimizing the ground reaction forces thus stabilizing the hindfoot. During eversion of the calcaneus, the talar head rotates internally by minimizing the stabilization force, but maximizing the rotatory and ground reaction forces, that is, this position is the most unstable one (like in flatfeet) but the most adaptive one relative to the ground [136].

28.9.1 Anatomy

The talonavicular and the calcaneocuboid joints form an articular space that crosses the whole foot, thus providing a technically easy plane for amputations. This was first described by François Chopart (1743–1795) [137]. It corresponds to the limit between the anatomical hindfoot and the midfoot.

The talonavicular and calcaneocuboid joints have different functions. The talonavicular joint belongs to the talocalcaneonavicular joint, the so-called "coxa pedis," which is essential for pronation and supination of the whole foot. The more rigid calcaneocuboid

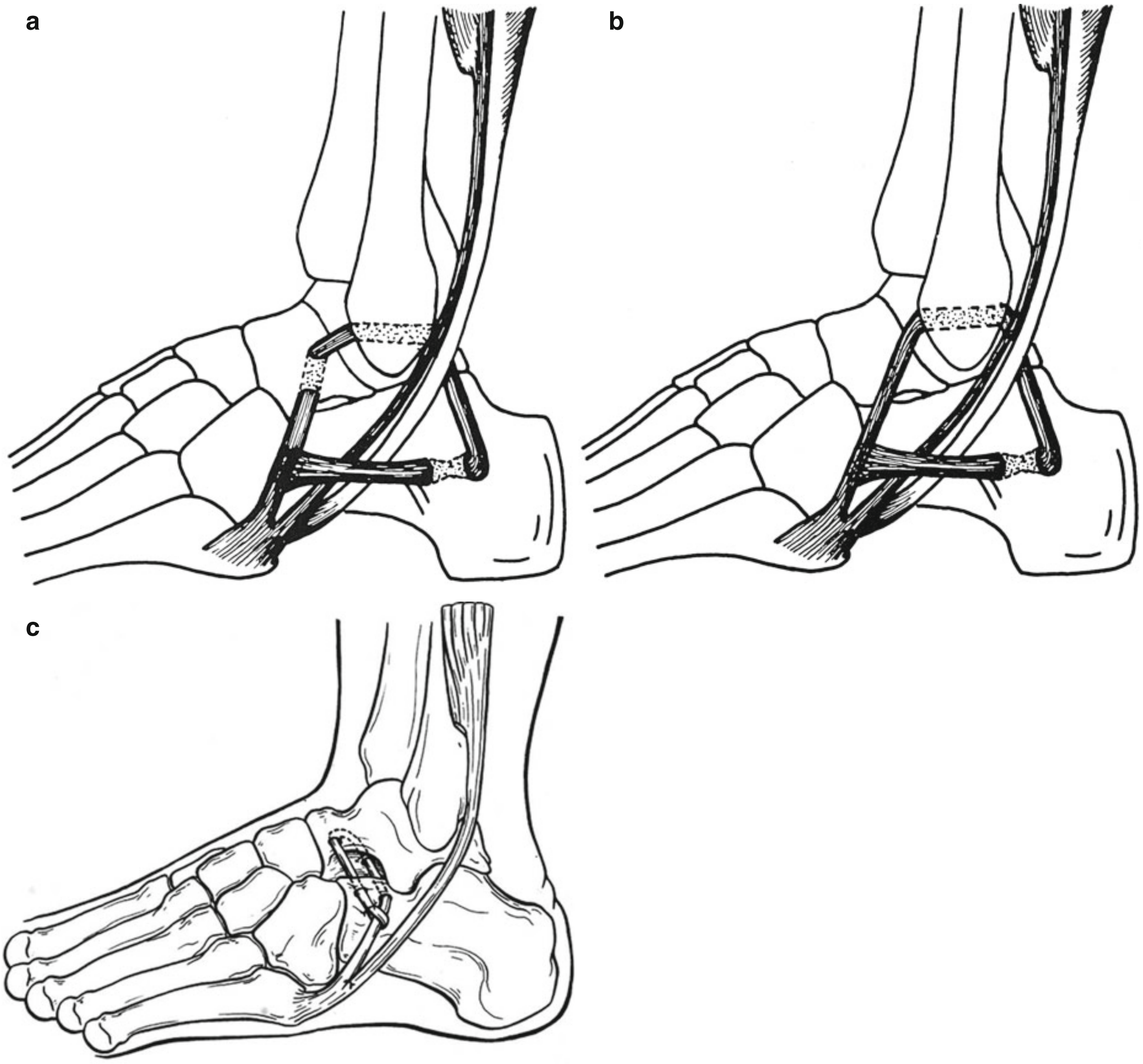

Fig. 28.19 The Chrisman-Snook tenodesis is a modified Elmslie procedure as salvage in case of recurrence of chronic combined anterolateral instability of the ankle and subtalar joint (**a**), without going through the talus for isolated subtalar joint instability (**b**). For isolated subtalar joint instability, the more anatomic procedure according to Pisani [134] with half of the peroneus brevis tendon is recommended (**c**) (From Zwipp [4])

joint, which has its own articular chamber, adapts the lateral column of the foot to the plantar buttress. On the plantar side of the cuboid lies the peroneal sulcus, which acts as a groove for the long peroneal tendon.

The navicular is the keystone of the longitudinal arch of the foot. The navicular is broader and shorter than the cuboid and articulates with three joint facets of the cuneiforms distally, the so-called innominate joint. On the medial side of the navicular tuberosity inserts the posterior tibial tendon, which is important for the maintenance of the longitudinal foot arch. The longitudinal foot arch is dynamically stabilized by the posterior tibial tendon. The bifurcate ligament that runs from the anterior calcaneal process to the navicular and cuboid is the pivot point and stabilizer of the Chopart joint.

Ligaments that stabilize the Chopart joint are the dorsal talonavicular ligament and the plantar calcaneonavicular ligament. The latter is also known as the spring ligament. The movement of the Chopart joint is discordant to the subtalar joint.

The cuboid articulates with the fourth and fifth metatarsals, the lateral cuneiform, and the anterior

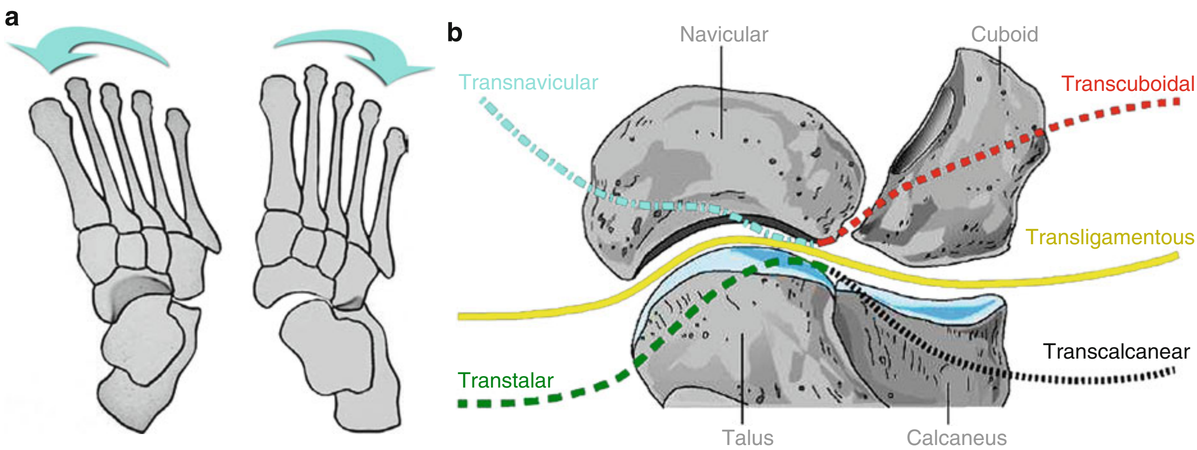

Fig. 28.20 The principal injury mechanisms of Chopart dislocation fractures are shown. Compression fractures at one foot column (e.g., medial) leads to occult ligament injury of the contralateral foot column (e.g. lateral) (**a**). Contralateral Chopart dislocation fractures according to the type of dislocation force (From Wirth and Zichner [138]) (**b**)

calcaneus. Little motion occurs at the metatarsal cuneiform junction or intercuneiform articulation. There is motion at the calcaneocuboid joint, as this joint moves during inversion and eversion of the foot. The length of the cuboid contributes to the length of the lateral column of the foot. The inconsistent os peroneum is found in the peroneus longus adjacent to the cuboid.

28.9.2 Organ-Related Disease

28.9.2.1 Epidemiology/Etiology

The navicular bone is subject to two types of fractures: acute fractures including avulsion fractures and stress fractures. Both injuries are rare, but when they occur, they can be serious and potentially disabling. The classical mechanism of dislocation in the Chopart joint is a forced abduction or adduction of the forefoot with a fixed hindfoot (Fig. 28.20a). Severe abduction of the forefoot with axial loading of the fourth and fifth metatarsals produces a compressive force on the lateral column. The cuboid is caught in a “vise” or “nutcracker” between the metatarsal bases and the calcaneus. The cuboid then fails in compression.

Main and Jowett classified the injuries of the Chopart joint according to the direction of applied force: axial (40 %), medial (30 %), lateral (17 %), plantar (7 %), and crush (6 %) [31]. An often-unidentified fracture subluxation of the Chopart joint with minimum bony fragments is seen in women in midlife, caused by a low-energy trauma like a false step, a stair drop, or fall.

Compression or avulsion fractures of the navicular or cuboid often cause ligament injuries on the opposite side because of the functional unit of the talonavicular and the calcaneocuboid joint [139] (Fig. 28.20a). Eichenholtz and Levine [140] divided navicular fractures into tuberosity fractures, dorsal lip fractures, fractures of the body, and stress fractures. The fractures of the body have been further subdivided into nondisplaced and displaced fractures. The displaced fractures are then subdivided into type I (coronal plane fracture line with a large dorsal fragment), type II (oblique dorsoplantar fracture with a large medial fragment), and type III (central comminution with naviculo-cuneiform disruption). An additional fracture of the body occurs in conjunction with forefoot disruption [141].

Six typical forms of Chopart dislocation fractures are divided according to the dislocation force on that joint, including transligamentous as type I, transcalcanear as type II, transcuboidal as type III, transnavicular as type IV, transtalar as type V, and combination injuries of type 2–5 as type VI [4] (Fig. 28.20b). Fracture dislocations of the Chopart joint are often overlooked or suboptimally treated.

28.9.3 Diagnosis

28.9.3.1 Recommended European Standard Diagnostic Steps of Investigation

Mechanism of injury should be investigated. Swelling of the midfoot, possibly with associated deformity is seen. Open wounds should be noted. The neurovascular status of the foot should be documented. Compartment syndrome is common and should not be overlooked. Dorsoplantar with 30° craniocaudal tilted x-ray tube, oblique and lateral views are obtained as standard radiographs. Avulsion fracture of the dorsal talonavicular ligament over the talar neck was found to be an indirect and subtle sign of a transligamentous Chopart dislocation [142].

28.9.3.2 Additional Useful Diagnostic Procedures

CT imaging allows precise preoperative planning.

28.9.4 Therapy

28.9.4.1 Surgery: Recommended European Standard Surgical Procedures

The basic principle is reestablishing the anatomical orientation of the foot by immediate reduction of any dislocation. In cases of impaction causing malalignment, open reduction and restoration of the correct alignment is performed. The surgical approaches should allow for simultaneous open visual control of the lateral navicular and the calcaneocuboid joint. Priority is given to the anatomical reconstruction of the talonavicular joint, which might require reconstruction of both the talar head and the navicular bone.

28.9.4.2 Additional Useful Surgical Procedures

After osteosynthesis, ligament instabilities are treated. If a lateral or medial rotational instability in the talonavicular joint, so-called swivel dislocation [31], persists after osteosynthesis, temporary K-wire transfixation of the involved joint is recommended for 6 weeks during ligament healing. Temporary external tibiometatarsal transfixation for 6 weeks is required for complex and comminuted injuries in addition to transarticular K-wires [143].

28.9.5 Prognosis

For best results, Chopart dislocation fractures should be recognized early [144]. Painful chronic ligament instability can be caused by initially overlooked ligament injury. Only pure ligament injuries have good results with conservative treatment. Post-traumatic arthritis is seen after joint involvement [145]. Crush injuries with joint destruction have a poor prognosis, resulting in chronic swelling, pain, and limitation of movement [31]. Early anatomic (open) reduction and stable (internal) fixation minimize long-term impairments [146, 147]. A correlation was seen between correct medial and lateral column lengths and good functional results [146].

28.9.6 Complications

Infection, thrombophlebitis, compartment syndrome, and injury of the deep and superficial peroneal nerves can occur [148]. In older patients, avascular necrosis of the navicular may be seen, because of the critical blood supply to this bone. Infections are often seen with delayed treatment [143].

28.9.7 Exemplary Surgical Procedures

28.9.7.1 Transnavicular Chopart Dislocation Fractures (Type IV)

Via a dorsal approach, for better visualization a small distractor can be used between the head of the talus and the medial cuneiform. Anatomical reduction and screw osteosynthesis for simple fractures and posterior tibial tendon avulsion fractures are recommended. In some cases, a large bone defect is seen. Therefore, bone grafting may be necessary after reduction, followed by plate osteosynthesis.

28.9.7.2 Transtalar Chopart Dislocation Fractures (Type V)

Via an anteromedial approach, if the head of the talus is fractured, screw osteosynthesis is recommended. The screw heads may need to be countersunk under the cartilage. For large central defects, bone grafting and plate osteosynthesis is required.

28.9.7.3 Transcalcaneo- and Trans-Cuboideal Chopart Dislocation Fractures (Type VI)

A straight lateral approach for the calcaneocuboid joint is recommended. A distractor is useful. Often, impaction zones in the anterior process of the calcaneus

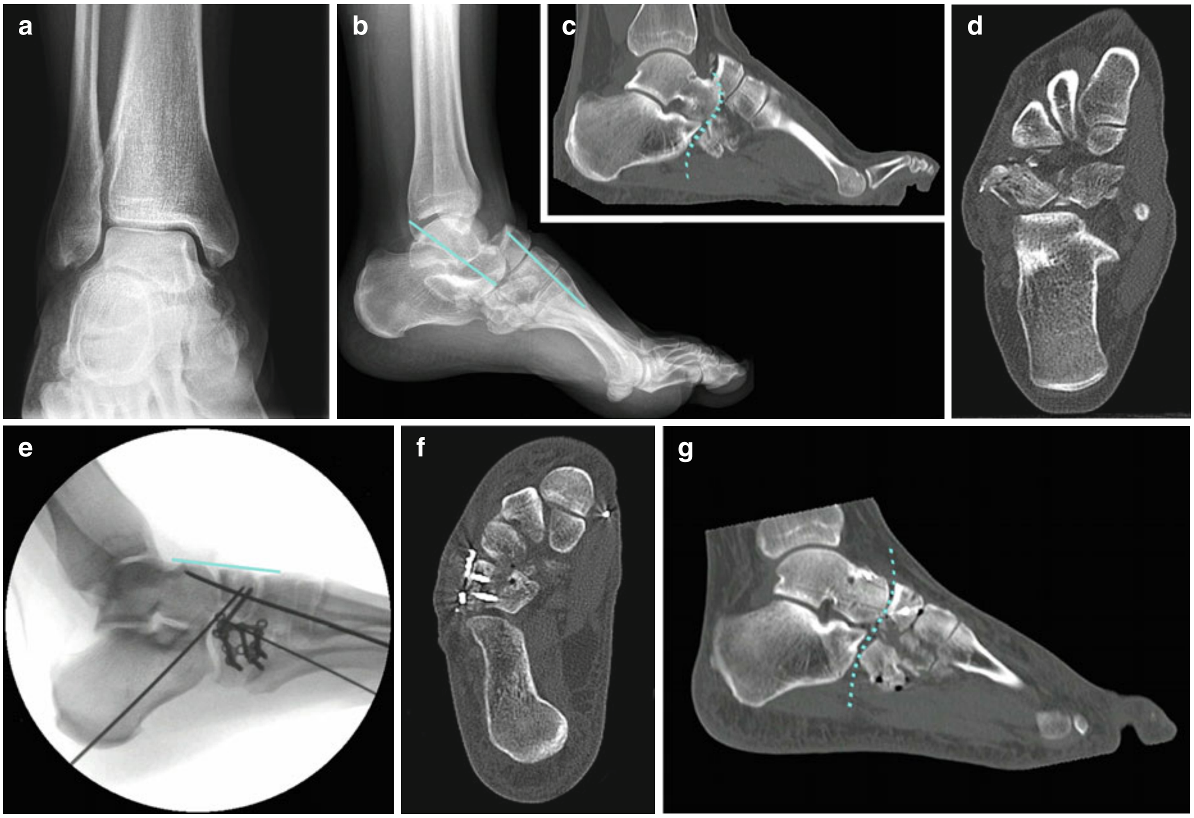

Fig. 28.21 A transnavicular and transcuboidal Chopart dislocation fracture, type VI according to Zwipp, is seen in the anteroposterior (**a**), lateral (**b**, **c**), and axial (**d**) views. The dislocation in the talonavicular joint leads to an interruption of the Cyma line (**b**, **c**). This patient was operated as an emergency with open reduction, plate osteosynthesis of the cuboid fracture, screw osteosynthesis of the navicular fracture, and temporary fixation of the talonavicular joint with a K-wire for 8 weeks (**e**). Postoperative CT scans show an anatomic reduction of the Chopart joint (**f**, **g**)

or the cuboid persist, requiring iliac crest bone grafting to elevate the impaction and restore lateral column length. Fixation is performed with screws or a plate, depending on fracture morphology and size of the fragments (Figs. 28.21 and 28.22). For combined injuries, a bilateral approach with enough soft tissue skin bridge is used.

28.9.8 Postoperative Management

The injured foot is placed postoperatively in a split non-weight-bearing below-the-knee plaster cast for 8–10 days. After removal of suture material, this is changed to a light below-knee walking cast. Weight bearing is limited to 15–20 kp for 6 weeks. After 6 weeks, removal of K-wires and/or external fixation is performed [143]. Stepwise increase of weight-bearing follows according to the type of fracture over the next 3–6 weeks. Physiotherapy includes intensive movement exercises, lymph drainage, and gait training as well as manual mobilization.

28.10 Reconstruction of the Chopart Joint

Secondary reconstruction of the Chopart joint includes ligamentoplasty and anatomic reconstruction of involved joints if possible. In case of nonreconstructable, malunited, or nonunited joints, resections and interposition plasty or fusions of the talonavicular, the calcaneocuboidal, or both (i.e., the Chopart's joint) is recommended.

28.10.1 Organ-Related Disease: Definition of the Disease

Malpositions of the Chopart joint can have the following characteristics [73]:

- Joint incongruency
- Horizontal malposition (adduction or abduction)
- Sagittal malposition (planus or cavus)
- Ligamentous instability

28.10.2 Epidemiology/Etiology

Injuries of the Chopart joint have a relatively low incidence, therefore, they are overlooked or inadequately managed in one-third of all cases [31, 145]. Even minimal joint incongruence can cause arthritis. Disruption of the normal relation between the lateral and medial foot columns results in severe structural disturbance of the whole foot [149].

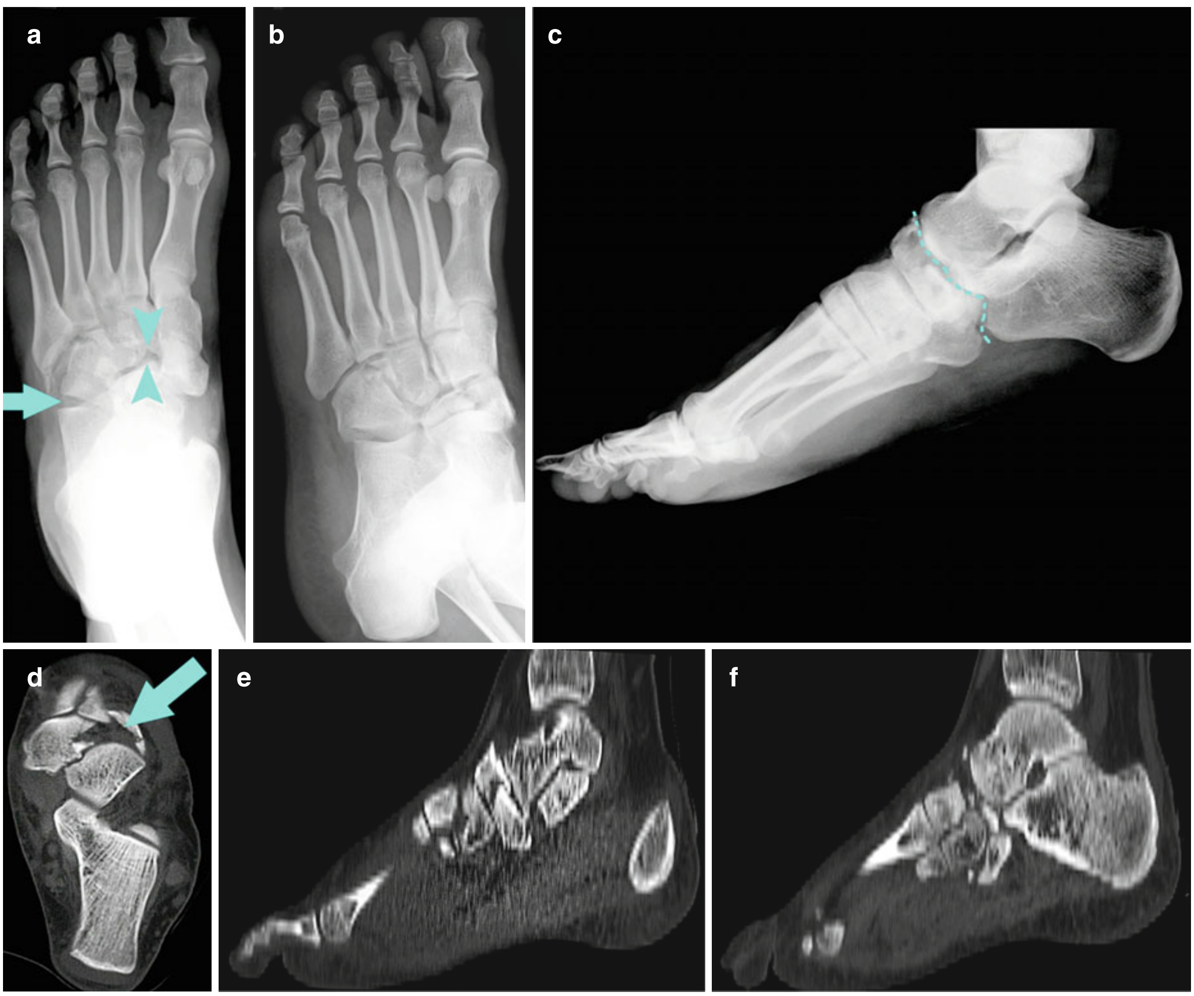

Fig. 28.22 A transnavicular and transcuboidal Chopart dislocation fracture as type VI according to Zwipp is shown in the dorsoplantar (**a**), lateral (**b**, **e**, **f**), oblique (**c**) and axial (**d**) views. A dislocation of the calcaneo-cuboidal joint is visible (*arrow* in **a**). Furthermore, the lateral view reveals an inhomogenous Cyma line (*dotted line* in **c**). The dorsoplantar view shows a slight varus position of the talometatarsal axis, as a result of an adduction injury mechanism (medial force). Open reduction via bilateral approach and internal fixation with plates as well as temporary fixation of the talonavicular and calcaneocuboidal joints for 6 weeks was performed (**g–i**). Additionally, bone grafting from the iliac crest was necessary for reconstruction of the cuboid. Postoperatively, a homogenous Cyma line is seen in the lateral view (**h**). The talometatarsal axis has been corrected (**g**)

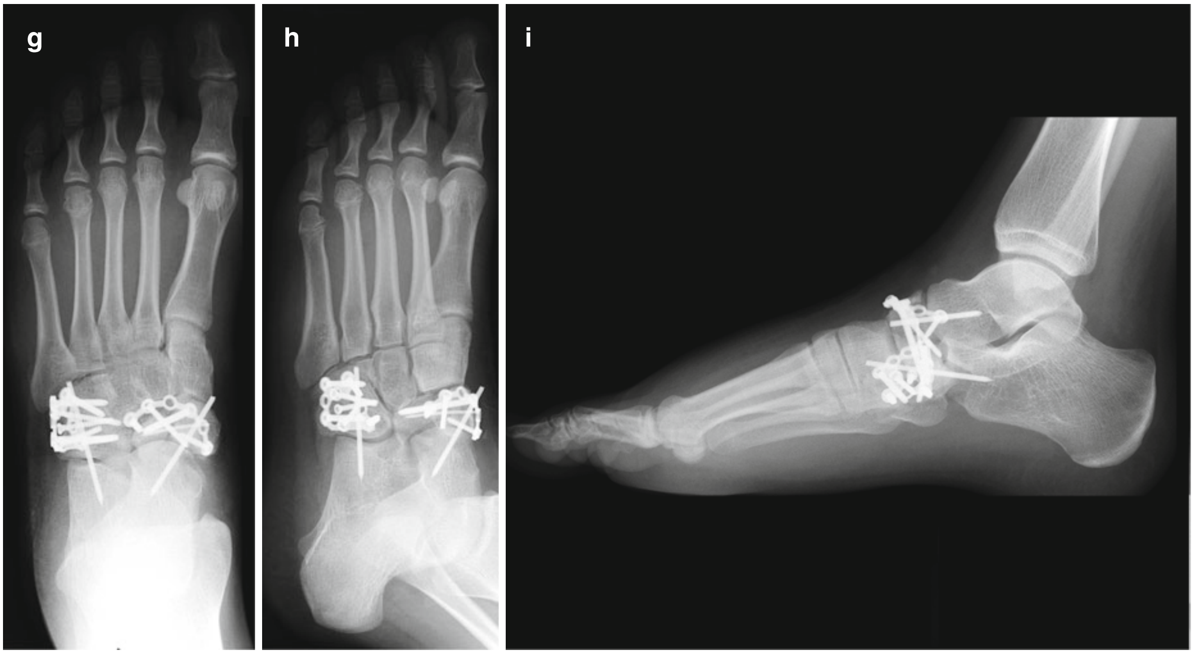

Fig.28.22 (continued)

Shortening of the lateral or medial foot column are caused by impaction zones in the head of the talus/navicular and/or anterior process of the calcaneus or cuboid resulting in a pes adductus or abductus [150]. Shortening of the medial column can be seen after avascular necrosis of the navicular. In addition, internal rotation of the talus causes a stepwise collapse of the longitudinal arch, leading to painful post-traumatic pes planus [73].

28.10.3 Symptoms

A variety of symptoms can be presented, such as chronic swelling and pain, limitation of movement due to the disordered biomechanics of the forefoot and midfoot, pes planus deformity, and chronic painful calcaneocuboidal instability.

28.10.4 Diagnosis: Recommended European Standard Diagnostic Steps of Investigation

The following X-ray analysis is recommended: dorsoplantar and lateral weight-bearing views of both feet, axial view of the hindfoot, so-called "Saltzman view" [110], and oblique view of both feet. CT scanning is necessary for preoperative planning.

28.10.5 Therapy

28.10.5.1 Surgery: Recommended European Standard Surgical Procedures

In selected cases without signs of post-traumatic arthritis or avascular necrosis, corrective osteotomies with joint preservation, anatomical realignment, and secondary osteosynthesis are possible [150]. For isolated calcaneocuboid arthritis, one should use the lateral approach and perform a calcaneocuboid arthrodesis [139]. If there is shortening of the lateral column, an interposition of tricortical bone graft is required. Crossed or parallel 3.5-mm or 4.5-mm cortical screws are used for fixation. Alignment of the talonavicular joint should be restored. Shortening of the medial column and isolated talonavicular arthritis require talonavicular arthrodesis (Fig. 28.23). However, this leads to movement limitation in the subtalar joint as well as decreased plantarflexion [151].

A dual approach is used to perform a talonavicular fusion and a calcaneocuboid fusion. Double arthrodesis


a
b
c
L
d
R
e
f
g

is indicated in calcaneocuboid and talonavicular joint arthritis as well as sagittal malposition in the Chopart joint. Severe pes planovalgus is an indication for triple arthrodesis [14]. This is recommended in cases with associated rupture of the posterior tibial tendon [31].

28.10.6 Complications

Complications include secondary post-traumatic arthritis.

28.11 Calcaneocuboidal Instability

Malgaigne, in 1843 [152], described first a case of "luxatio mediotarsalis." If ruptures of the calcaneocuboidal ligaments or the bifurcate ligament are overlooked or insufficiently treated, chronic instability may occur.

28.11.1 Definition of the Disease

The Andermahr classification of calcaneocuboidal ligament injuries [153] is as follows:

- Type I: distortion or partial rupture of the dorsal calcaneocuboidal ligament
- Type II: isolated rupture of the dorsal calcaneocuboidal ligament
- Type III: rupture of the dorsal calcaneocuboidal ligament and the bifurcate ligament, bony avulsion
- Type IV: rupture of the dorsal calcaneocuboidal, bifurcate and plantar ligament, compression fracture of the cuboid

28.11.2 Epidemiology/Etiology

Complete dislocations in the Chopart and Lisfranc joint are rare, because of the strong ligamentous connections and congruent joints [154]. Complete ligamentous dislocations have the same injury mechanism as the Chopart and Lisfranc dislocation fractures [5].

Along the Hellpap's supination line [119], injuries to the calcaneocuboidal joint ligaments can originate from different kinds of mechanisms, which manifest as an isolated or combined lateral instability of two (subtalar and calcaneocuboidal) or three (fibulotalar, subtalar, and calcaneocuboidal) planes [4]. Continued trauma can cause additional injury of the bifurcate ligament or fifth metatarsal base fractures, located at one end of the supination line.

28.11.3 Symptoms

Symptoms are submalleolar pain, hematoma, and tenderness over the lateral calcaneocuboidal joint.

28.11.4 Diagnosis: Recommended European Standard Diagnostic Steps of Investigation

Exclusion of a Chopart fracture by 30° dorsoplantar, lateral, and 45° oblique radiographs. Verification of a calcaneocuboidal instability: dorsoplantar weight-bearing views with 30° tilted tube. Under regional anesthesia, stress X-rays in the TELOS suspensory machine with 15 kp varus stress at the Chopart joint. A calcaneocuboidal tilt of 5° is diagnostic confirmation of calcaneocuboidal instability. In addition, capsular or ligamental avulsion fractures at the Chopart joint also suggest calcaneocuboidal injury. Medial instability of the Chopart joint should also be sought by using the TELOS apparatus to apply a varus stress on the forefoot while the hindfoot is fixed.

28.11.5 Therapy

28.11.5.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

Nonoperative treatment is recommended for Andermahr classification type II. Isolated calcaneocu-

Fig. 28.23 Preoperative weight-bearing X-rays in the dorsoplantar (**a**), anteroposterior (**b**) as well as lateral views (**c**, **d**) show a dorsal dislocation of the navicular (*line* in **c**) resulting from its collapse combined with a talonavicular arthritis, a pes cavus (**c**), and a severe adduction of the foot (**a**). Intraoperatively, correction of the foot axis and talonavicular arthrodesis has been performed with bone grafting from the iliac crest and screw osteosynthesis. Postoperative X-rays (**e**–**g**) show a bony consolidation of the arthrodesis, a correction of the adductus deformity (**e**), and a reduced navicular (*line* in **g**) boidal instability is treated in a split below knee cast for 3–5 days and followed by an ankle orthosis. Undisplaced avulsion fractures of the bifurcate ligament at the anterior calcaneal process or the mediodorsal calcaneonavicular ligament (synonym: neglect ligament), could be treated in a split below knee cast with limited weight-bearing of 20 kp for 6 weeks [124]. Physiotherapy with conditioning of the pronators and proprioceptive training is the gold standard after immobilization.

28.11.6 Surgery: Recommended European Standard Surgical Procedures

Andermahr classification types III and IV require surgical treatment. Isolated chronic calcaneocuboidal instability with arthritis requires a calcaneocuboidal arthrodesis (Fig. 28.24). Isolated chronic calcaneocuboidal instability without arthritis can be treated with peroneus brevis tenodesis or a crossed tendon plasty for the lateral stabilization of the calcaneocuboidal joint [129, 153]. Combined instability in two or three planes should be treated with the modified Elmslie procedure [4] (Fig. 28.19).

28.11.7 Differential Diagnosis

The Chopart fracture/dislocation is present.

28.11.8 Prognosis

Correct diagnosis and therapy of ligamentous injuries with or without bony avulsions have an excellent prognosis [139]. Persistent ligamentous instability or loss of function of the neglect ligament must be treated with arthrodesis (talonavicular, Chopart or triple arthrodesis) [31, 155].

28.11.9 Complications

Undiagnosed avulsion fractures of the bifurcate ligament at the anterior calcaneal process can cause painful malunion or nonunion. Chronic instability can lead to arthritis in the calcaneocuboidal joint.

28.12 Lisfranc Dislocations and Fracture Dislocations

The Lisfranc joint connects the midfoot to the forefoot. The key of a stable link is given mechanically by the base of the second metatarsal locked in between the first and third cuneiform and functionally by the strong "Lisfranc ligament." Malgaigne in 1843 [152] was the first to describe 22 cases of a dislocation of the Lisfranc joint.

28.12.1 Definition of the Disease

The Quénu and Küss classification [156] of the Lisfranc dislocation fractures: homolateral, divergent, and isolated injuries (Fig. 28.25). The homolateral dislocation fractures are encountered in 68 %, but isolated injuries are observed in 27 % and divergent dislocation fractures only in 5 % [4].

Hardcastle and colleagues [157] modified the Quénu and Küss classification in an ABC classification: total lateral or dorsoplantar incongruence as type A1 or A2, respectively, partial medial or lateral incongruence as type B1 or B2, respectively, and divergent injury with partial or total dislocation as type C1 or C2, respectively. The AO classification contains pure dislocation as type D [16].

28.12.2 Epidemiology/Etiology

Injury to the Lisfranc joint commonly affects males, frequently during the third decade of life [7, 158]. The most frequent cause is a high velocity trauma, 50 % are caused by vehicular accidents [4]. Nine to seventeen percent of injuries are open [159]. Injuries range from simple dislocations or ligamentous injury to complete destruction of the joint accompanied with severe soft tissue damage caused by crushing.

Direct force, such as crush injuries, causes plantar dislocation of the metatarsals in the horizontal plane [160] (Fig. 28.25). Indirect injuries are more common and produced by axial force and simultaneous plantar flexion of the foot, which may be from a fall from height or extrinsic heel load with the foot in fixed plantar flexion, occurring in football (Fig. 28.25). Being thrown from a horse with the foot left in the stirrup

Fig. 28.24 Idiopathic calcaneocuboidal arthritis is shown in the dorsoplantar (**a**) and lateral (**b**) views, which was treated with an arthrodesis realized with a locking x-plate (**c**–**e**)

may cause fractures of the base of the second metatarsal, the cuboid, and the metatarsal necks. Deceleration trauma or twisting injuries in dancers are other possible causes.

Type B2, according to the modified Hardcastle classification, is reported as the most common [161]. Because of the weaker dorsal ligaments, dorsal dislocation of the metatarsals occurs in 97 % of all cases. Only 10 % of all cases are subtle pure ligamental injury. Commonly, a fracture of the base of the second metatarsal is the basis for subluxation in the Lisfranc joint.

If the perpendicular distance between the distal articular surfaces of the medial and middle cuneiform is small, then this is a risk factor for Lisfranc dislocations. A dorsolateral subluxation of the second metatarsal of only 2 mm causes a decrease of 35.5 % of the tarsometatarsal contact surface.

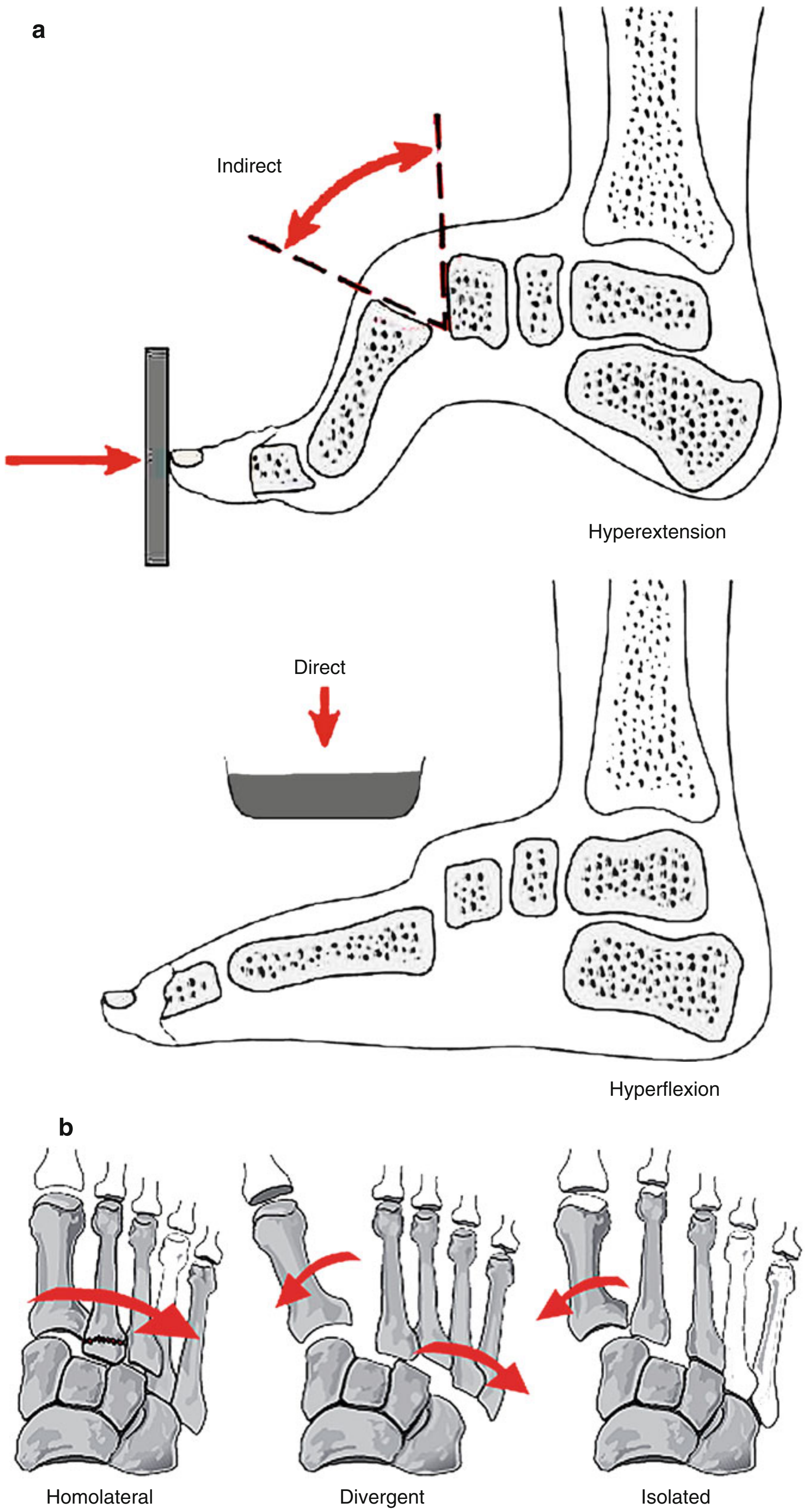

Fig. 28.25 Injury mechanisms of the Lisfranc joint are shown in the sagittal plane (**a**). In addition, an abduction/or adduction of one or more rays occurs in the horizontal plane. Classification of Lisfranc dislocation fractures according to Quénu and Küss [156] (**b**) (From Wirth and Zichner [138])

Fig. 28.26 Typical plantar ecchymosis (**a**, **b**) extending to the lateral hindfoot (**c**) of a patient with Lisfranc dislocation fracture is shown

28.12.3 Symptoms

Symptoms vary from diffuse pain without external injury to severe dislocation with soft tissue damage in association with open fractures, skin necrosis, compartment syndrome, or focal tenderness along the tarsometatarsal joints. Vague midfoot pain needs clarification, because persistent subluxations can result in chronic instability with persistent pain and progressive deformity. The presence of plantar ecchymosis indicates a rupture of the plantar ligaments [162] (Fig. 28.26). Plantar dislocation of the metatarsals often produces a noncorrectable claw toe position.

28.12.4 Diagnosis

28.12.4.1 Radiology

The dorsoplantar view is required, with 20° craniocaudal tilted X-ray tube of the whole foot as well as 45° oblique view of the midfoot. The normal anatomic findings are the following: the medial side of the base of the fourth metatarsal aligns with the medial side of the cuboid; the lateral side of the base of the third metatarsal aligns with the lateral side of the third cuneiform; the second metatarsal aligns accordingly with the intermediate cuneiform as well as the first metatarsal with the first cuneiform medially and laterally.

A distance of more than 3 mm between the bases of the first and second metatarsals in the dorsoplantar view indicates an injury of the Lisfranc ligaments. A projection of the fifth metatarsal base in relation to the edge of the cuboid is not a reliable indication for a dislocation in the Lisfranc joint. The “fleck sign” refers to the presence of a small bony fragment between the base of the second metatarsal and the medial cuneiform and represents an avulsion of either the proximal or distal attachment of the Lisfranc ligament correlating with a Lisfranc dislocation in 90 % of cases [160, 163].

If there is a suspicion of instability despite normal standard radiographs, weight-bearing lateral and dorsoplantar views of the foot under local or regional anesthesia would be indicated [7, 158]. Suspicion of horizontal instability necessitates forced abduction and adduction views under local anesthesia [4]. It is useful to x-ray both feet for comparison.

28.12.4.2 Recommended European Standard Diagnostic Steps of Investigation

If there is any suspicion, compartment pressure should be measured; with a pressure over 25 mmHg, dermatofasciotomy should be performed.

28.12.4.3 Additional Useful Diagnostic Procedures

CT scanning for preoperative planning: 3D CT imaging provides a comprehensive evaluation of the injury for optimal treatment planning [7]. MRI has a high sensitivity for subtle ligament injuries, but it is not usually indicated for acute diagnosis [164].

28.12.5 Therapy

28.12.5.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

There is little place for nonoperative treatment. It is only for the rare isolated ligamentous dislocations, which can be stably reduced under fluoroscopic control.

Closed reduction and temporary immobilization in a plaster or transfixation is sometimes indicated in polytraumatized patients, where life-sustaining measures are required or if there are contraindications to surgery.

Under local or general anesthesia, with fluoroscopic control, an axial force is applied to the forefoot with the lower leg fixed. Then, depending on the direction of dislocation, forced abduction or adduction with simultaneous plantar or dorsiflexion is applied for reduction. The bases of the metatarsals are reduced with direct digital pressure distal to the tarsal bones.

The injured foot is then placed in a split, non-weight-bearing below-the-knee plaster cast for 8–10 days until the soft tissue swelling settles. Thereafter, change to a below-the-knee walking cast for 6 weeks with weight-bearing limited to 15–20 kp [4, 148].

28.12.5.2 Additional Useful Therapeutic Options

Dermatofasciotomy in case of additional foot compartment syndrome with secondary suture after reduction of swelling. If this is not possible, mesh grafting or fasciocutaneous flaps may be required or even free flaps in significantly open fractures.

28.12.6 Surgery

28.12.6.1 Recommended European Standard Surgical Procedures

Because of the thin soft tissue envelope with a high risk of skin necrosis and the high incidence of compartment syndrome, Lisfranc fractures dislocations are emergencies. Therapy of choice is open reduction and internal fixation [148, 159].

Two parallel longitudinal dorsal incisions are made with a minimum 5 cm skin bridge. Dorsomedial approach allows relief of foot compartment pressure. Debridement of capsule and ligaments at the base of the second metatarsal, where in 90 % of all cases exists a Y-shaped or butterfly fracture, which is then stabilized by small screws [160].

Afterwards the reconstructed base of the second metatarsal is reduced and fixed with one or two temporary K-wires, then changed to a 3.5-mm cortical screw from the base of the metatarsal to the intermediate cuneiform without joint compression. The head of the screw is countersunk in the bone to avoid interference with the extensor tendons. The first, third, fourth and fifth ray are operated in a similar manner. A lateral approach for osteosynthesis is recommended for unstable fracture dislocation of the fourth and fifth tarsometatarsal joints (Fig. 28.27). This is to facilitate perpendicular screw or K-wire placement across of the cuboid. Depending on the direction of instability, an additional intercuneiform screw could be required. Advantages of K-wire osteosynthesis are a shorter operation time and smaller disruption of the joint surfaces (Fig. 28.28).

28.12.6.2 Additional Useful Surgical Procedures

Primary arthrodesis should be reserved only for severe destruction of joint surfaces, although some authors recommend it in severe ligamentous injury as well [165].

28.12.7 Prognosis

Prognosis depends on early and precise reduction as well as the stability of the osteosynthesis [166]. Comparable functional results have been shown for primary open reduction, internal fixation, and primary arthrodesis of Lisfranc dislocation fractures [167]. Good reduction is defined as a tarsometatarsal angle of not more than 10° in the lateral view and a distance between the base of the first and second metatarsals of not more than 2 mm [160]. Post-traumatic arthritis of the Lisfranc joints after a good reduction is present in 30–100 % [159, 160].

28.12.8 Complications

Closed reduction is often hindered by interposition of capsule, ligaments, or tendons [168]. K-wire osteosynthesis can be associated with migration, loss of reduction, and pin-site infection. Compartment syndrome occurs in two-thirds of all cases [169]. Delayed treatment can be associated with hammer toes and forefoot contraction, causing pain and difficulty with gait [161]. Deep infections may develop from skin necrosis as a consequence of delayed treatment and/or reduction. Occasional avascular necrosis of the head of the second metatarsal is seen. Complex regional pain syndrome type I [170] can also occur with unsatisfactory treatment.

28.12.9 Postoperative Management

After screw osteosynthesis, the patient is prescribed custom rigid-soled shoes. After K-wire osteosynthesis, the patient will need a below-knee walking cast. Weight bearing is limited to 15–20 kp for 6 weeks. Osteosynthesis material is removed after 8 weeks [166]. Weight bearing increases stepwise until the 10–12 weeks. Physiotherapy includes intensive range of movement exercises, lymph drainage, and gait training as well as manual mobilization of the tarsus [148].

28.13 Reconstruction of the Lisfranc Joint

The key to reconstruction is the anatomic reduction of the base of the second metatarsal into the space between the medial and lateral cuneiforms. This is the precondition to realign the whole Lisfranc joint. If possible the lateral Lisfranc joint (i. e., joints between the fourth and fifth metatarsals and the cuboid) should not be fused to preserve needed motion. If there is significant arthritis and the calcaneocuboidal joint is working normally it can be fused, but if the calcaneocuboidal joint is already fused, an interposition plasty with fascia is recommended.

28.13.1 Epidemiology/Etiology

Thirty percent of all cases are overlooked or incompletely reduced subluxations or dislocations. There is an incidence of 30 % of malposition after closed reduction and plaster treatment or K-wire osteosynthesis

Fig. 28.27 This patient was thrown from a horse, resulting in a homolateral Lisfranc dislocation fracture with fractures of the metatarsal bases 2 and 5 (**a**–**e**) and a fracture of the lateral cuneiform (*arrow* in **e**). Open reduction and screw osteosynthesis of the metatarsal bases 2 and 5 via dorsomedial and lateral approaches, followed by temporary K-wire fixation of the tarsometatarsal joints II and III (**f**, **g**). K-wires are removed after 8 weeks

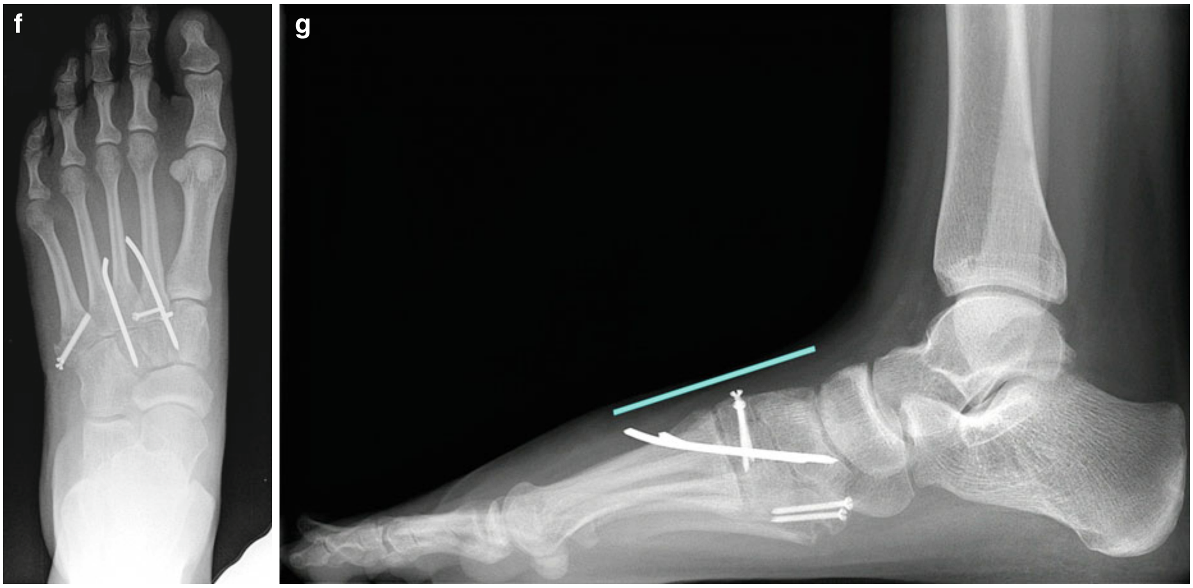

Fig. 28.27 (continued)

[170] (Fig. 28.29). Axial deviation of the forefoot, so-called pes abductus, causes abnormal weight-bearing in the forefoot and abnormal gait. If the situation persists it can lead to subluxation in the talonavicular joint and subsequent development of hindfoot valgus at the subtalar joint [166].

28.13.2 Symptoms

Painful deformity of the whole foot exists, which continues in a stepwise collapse of the longitudinal foot arch resulting in a painful post-traumatic pes planovalgus.

28.13.3 Diagnosis: Recommended European Standard Diagnostic Steps of Investigation

Dorsoplantar, lateral, and 45° oblique weight-bearing views of both feet are initial performed [170], whereas CT scans added for preoperative planning. The most important radiological feature of malposition as well as adequate reduction is the talometatarsal axis in both planes. The extent of uncovering of the talar head by the navicular in the dorsoplantar view shows the degree of subluxation [171].

The goal of surgery is the restoration of the normal axial and length relationship of the foot, allowing pain-free gait in a normal shoe. Corrective arthrodesis of the Lisfranc joint is performed.

28.13.4 Therapy

28.13.4.1 Surgery: Recommended European Standard Surgical Procedures

Two dorsal parallel longitudinal incisions are necessary for complete Lisfranc arthrodesis (Fig. 28.29). Partial Lisfranc arthrodesis is also possible, if the whole Lisfranc joint is not affected (Fig. 28.30). In many cases, the lateral column will realign after correction of the medial column and fusion can be limited to the first to third tarsometatarsal joints, and mobility of the fourth and fifth tarsometatarsal joints may be preserved [166].

The tarsometatarsal joints are debrided of cartilage and sclerotic subchondral bone after two dorsal parallel longitudinal incisions. Scar tissue between the first and second metatarsal bases needs to be debrided as well. If there is a big defect, a cortico-cancellous bone graft will be required, particularly if not all rays are shortened.

Correction of the axial deviation starts with the second ray. This then facilitates the reposition of the

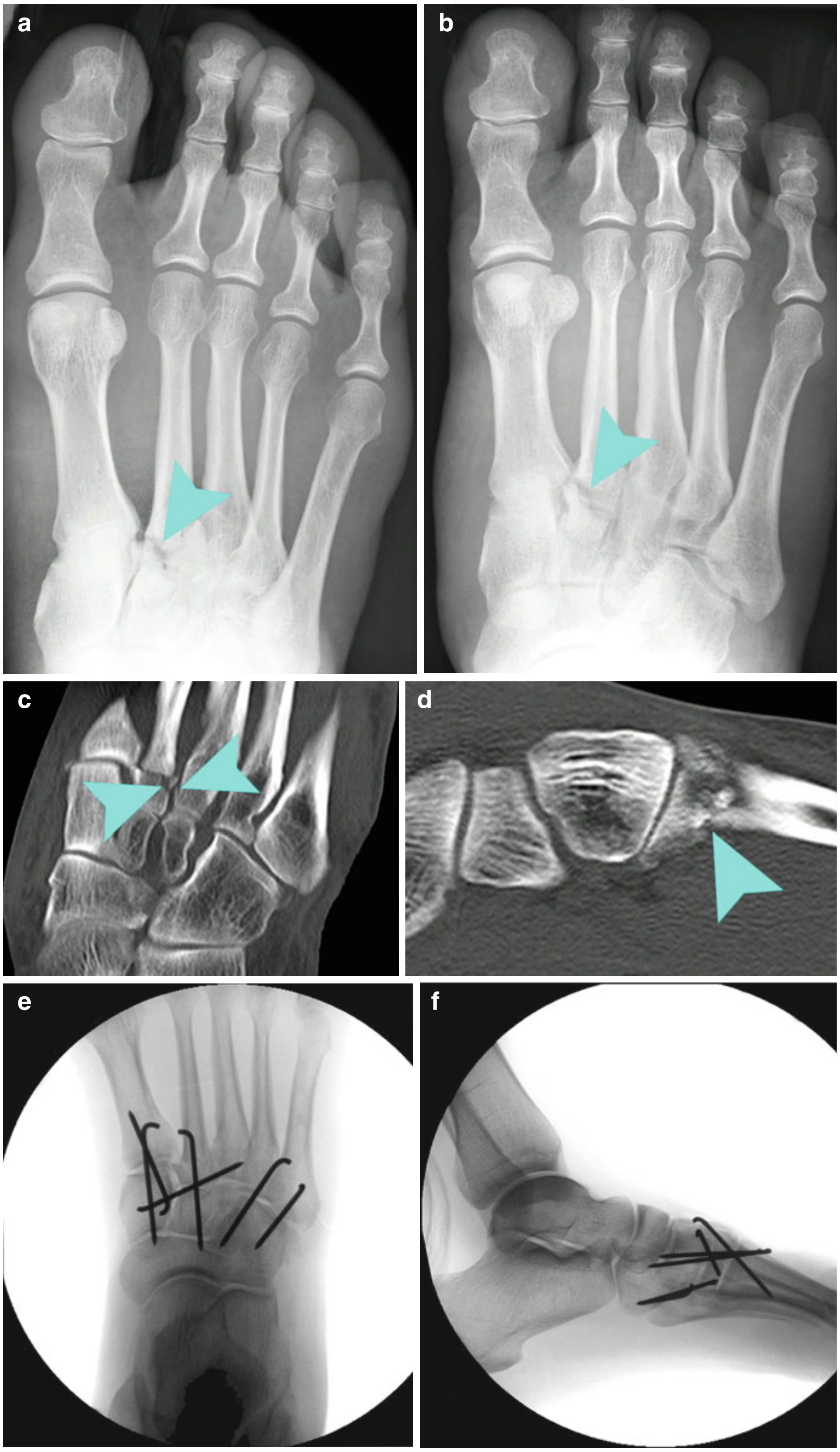

Fig. 28.28 The injury mechanism of this homolateral Lisfranc dislocation fracture was a fall while the foot was stuck in a fixed position in a tram rail. Radiological diagnostic showed a fracture of the metatarsal bases II and III (**a**–**d**). Open reduction via dorsomedial and lateral approaches over the metatarsals I and V as well as K-wire osteosynthesis were performed with temporary K-wire arthrodesis of the Lisfranc joint for 8 weeks (**e**, **f**)

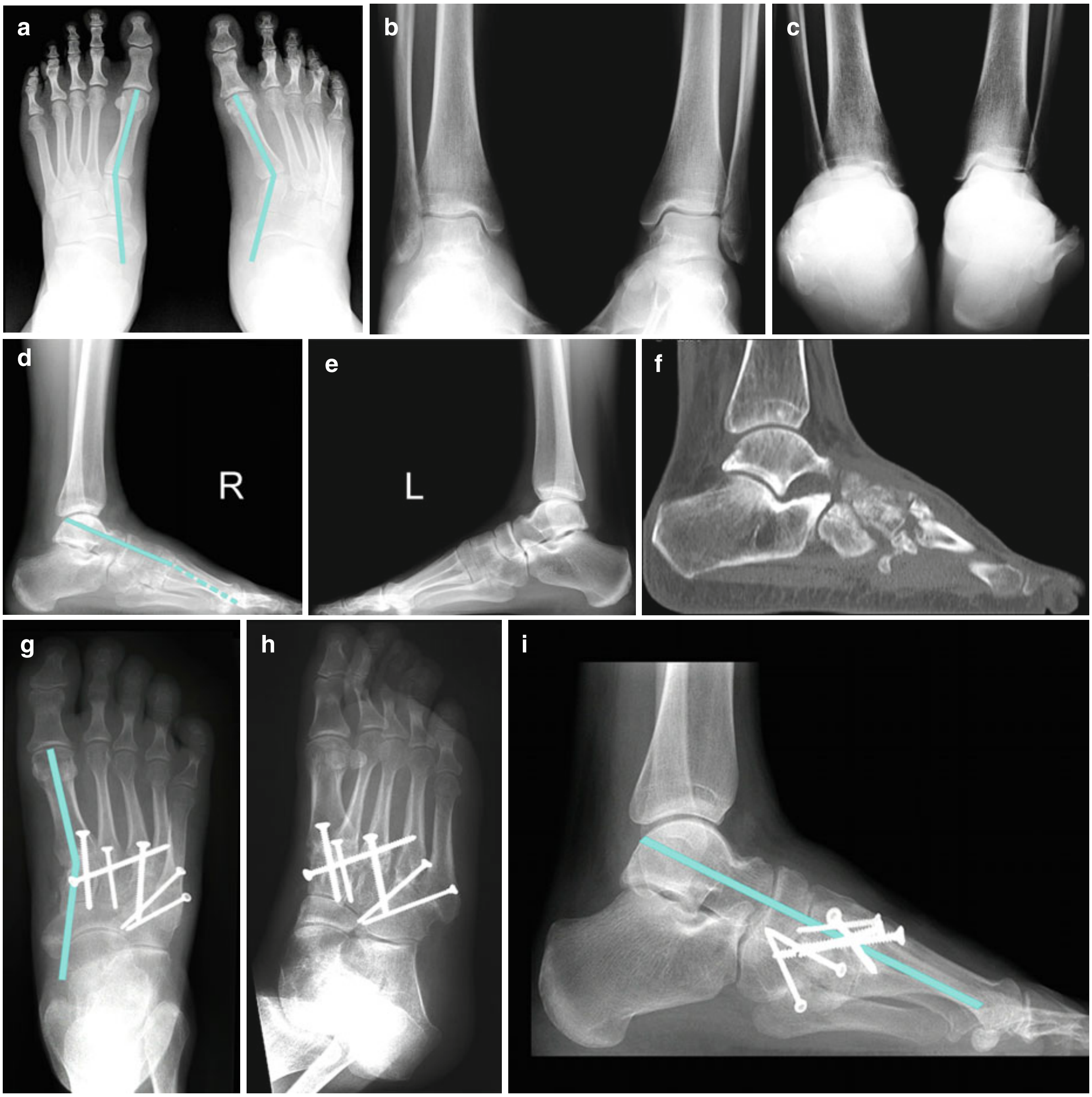

Fig. 28.29 Severe arthritis of the right Lisfranc joint resulting from joint incongruency (**a**, **d**, **f**) 1 year after homolateral Lisfranc dislocation fracture treated initially with minimally invasive K-wire osteosynthesis. Weight-bearing X-rays show an adduction deformity of the right foot in the dorsoplantar view (**a**), and a dislocated talometatarsal axis (*lines* in **a** and **d**) in comparison to the uninjured contralateral foot (**e**). Saltzman view shows a normal hindfoot axis of both feet (**c**). Similarly, weight-bearing views of the ankle joints show no joint incongruency (**b**). Reorientating arthrodesis of the complete Lisfranc joint has been performed with screws via dorsomedial and dorsolateral approaches under correction of the adductus deformity and the talometatarsal axis (*lines* in **g** and **i**)

adjacent third and first rays. Depending on the age of injury and degree of malposition, correction of the first three rays can be followed by spontaneous alignment of the other lateral rays [170]. Compression arthrodesis is done with 3.5-mm cortical screws (Fig. 28.29). Poor bone quality and large defects of more than 2 cm can be managed with bone grafting and plate osteosynthesis [171].

Postoperative management involves the use of a Lopresti slipper with full weight bearing for 6–8 weeks. Removal of the screws is not necessary if it is asymptomatic.

28.13.5 Prognosis

Good pain relief and high patient satisfaction can be expected. Correction is possible even many years after the initial injury [166, 170]. Nonunion occurs in 10 % of cases [166, 170, 171]. Patients should be informed of the possibility of asymptomatic screw fracture.

28.14 Fractures of the Metatarsals

The five metatarsals build, together with the adjacent toes, the forefoot. The fifth metatarsal is the most commonly fractured one in children and adults. In case of significant dislocation, its reconstruction is as important as that of the first one. Dislocated subcapital fractures should be reduced and fixed very early to prevent painful malunion. Jones fractures are special cases.

28.14.1 Definition of the Disease

Classification of metatarsal fractures: base, shaft, subcapital, and head fractures. Classification of fifth metatarsal fractures [172–174]: type I: avulsion fracture of the tuberosity, type II: fracture at the junction of the metaphysis end diaphysis, type III: stress fracture of the proximal shaft. Jones fractures [175] are defined as a transverse fracture 1.5–2.0 cm distal to the tip of the fifth metatarsal tuberosity at the metaphyseal-diaphyseal junction [176].

28.14.2 Epidemiology/Etiology

Chronic direct forces produce stress fractures; this commonly involves the proximal third of the shaft and the base of the second and fifth metatarsals. Approximately 45–70 % of all metatarsal fractures involve the fifth metatarsal [177, 178]. Athletic inversion-type injuries along the Hellpap supination line are a common cause of fractures of the fifth metatarsal, especially in soccer players [119, 179].

28.14.3 Symptoms

Symptoms include pain, swelling, ecchymosis, deformity, inability to bear weight, pain to passive motion, and crepitus over the respective metatarsal.

28.14.4 Diagnosis

Radiographic evaluation should include weight-bearing anteroposterior and lateral projections and 45° oblique views, because of overlap of the metatarsals in the lateral and dorsoplantar views. Precise adjustment and exposure of the radiograph is important to see hairline fractures. Metatarsal base fractures can be accompanied with instability in the Lisfranc joint. This may have to be ruled out with forced abduction-adduction projections under regional anesthesia.

Stress fractures are mostly diagnosed 2 weeks after onset of diffuse pain at the midfoot. Bone scintigraphy as well as MRIs are good modalities for the diagnosis of stress fractures [4]. Metatarsal fractures have to be differentiated from accessory bones such as the os vesalianum, os peroneum, os intermetatarseum, or os cuneometatarsal. Tuberosity fractures of the fifth metatarsal should be distinguished from the proximal fifth metatarsal apophysis, which appears between the ages of 9 (girls) and 11 (boys), and disappears 3 years later.

28.14.5 Therapy

28.14.5.1 Nonoperative Treatment

In principle, all metatarsal fractures without displacement or angulation can be treated conservatively [178, 180]. The injured foot is placed in a split, non-weight-bearing below-the-knee plaster cast for 3–5 days and then in a well-molded Lopresti slipper for 2–4 weeks [181].

If the patient is compliant, early functional treatment in special rigid-soled shoes with regular radiographic follow-up allows full weight bearing after 1–2 weeks [4]. Acute Jones fractures are treated most commonly with a short-leg non-weight-bearing cast for 8–10 weeks, because of poor blood supply and delayed union [174].

28.14.6 Surgery: Recommended European Standard Surgical Procedures

Dislocation of more than 3–4 mm or an angulation more than 10° are indications for surgery [178]. Early intramedullary screw fixation of Jones fractures as well as stress fractures, primarily in athletes, has offered slightly decreased union times, providing an earlier return to athletic participation.

Fig. 28.30 Post-traumatic arthritis of the medial Lisfranc joint is seen in a patient 1.5 years after a Lisfranc dislocation fracture resulting from a foot pedal slip off (**a**–**f**). In addition, the patient complained about a transfer metatarsalgia over the head of the third metatarsal. Weight-bearing views show a slight increased space between the first and second metatarsal of the left foot in the dorsoplantar view (**a**), but normal talometatarsal axes in the lateral views (**c**, **d**). Skyline view of the forefoot does not show a descended third metatarsal head (**e**). Preoperative CT scans show the typical fleck sign (*arrow* in **f**) and a reduced joint space between the intermediate cuneiform and the base of the second metatarsal (*arrowhead* in **f**). Partial screw arthrodesis of the medial Lisfranc joint has been performed (**g**, **h**)

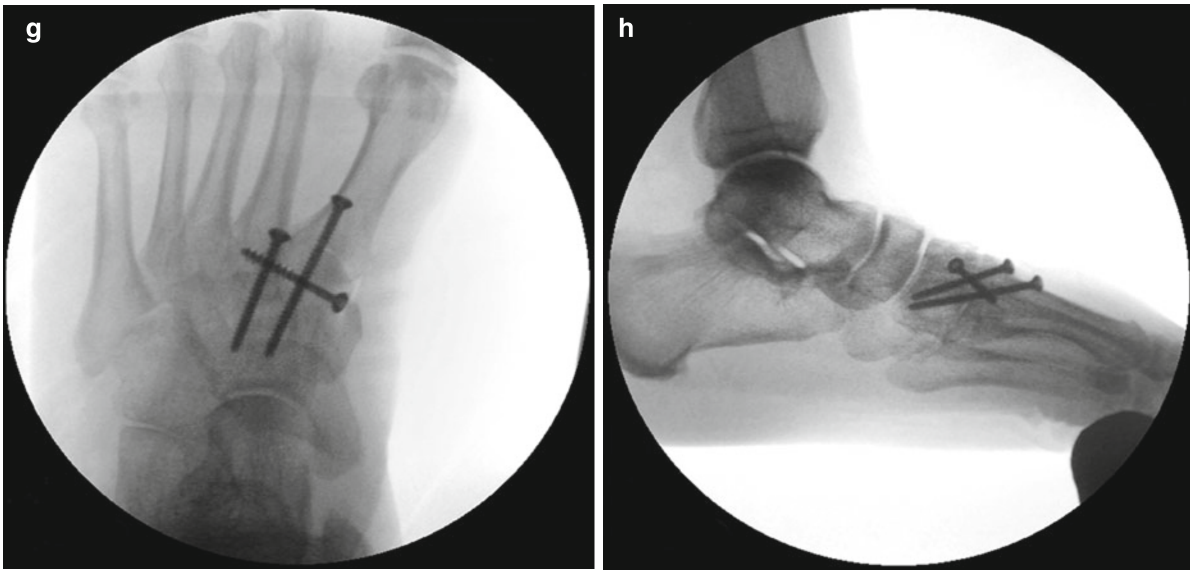

Fig.28.30 (continued)

Second–fourth metatarsal fractures: subcapital and diaphyseal fractures with displacement in the sagittal plane should be surgically treated [182]. Closed reduction with percutaneous pinning can be performed. Fixation methods include crossed K-wires, initially described for transverse fractures, and interfragmentary screws for oblique or spiral fractures [183].

Reduction is performed with antero (preferred) or retrograde insertion of the K-wire, which may include the metatarsophalangeal joint [184] (Fig. 28.31). Only displaced fractures of the metatarsal head should undergo open reduction and fixation with small screws or plates [4] (Figs. 28.32 and 28.33).

Good results have been obtained with insertion of two longitudinal K-wires into the medullary canal to provide additional stability. With the first and fifth metatarsal, dislocation in the frontal and sagittal planes is likely. If closed reduction is not possible, open reduction and osteosynthesis with two crossed K-wires or plate is recommended [56]. Juxta-articular avulsion fractures should stabilized with small screws [182]. Surgical intervention has been considered for fifth metatarsal fractures involving greater than 30 % of the articular surface or articular displacement more than 2 mm. These should undergo open reduction and stabilization with tension band wiring, screws, or small plates [184].

For the postoperative procedure, a Lopresti slipper is worn for 4–6 weeks with full weight bearing. An alternative treatment for fifth metatarsal base fractures is a Caligamed orthesis that limits supination [185].

28.14.7 Prognosis

If conservative therapy of a fifth metatarsal fracture leads to a nonunion, debridement of the sclerosed medullary cavity and tension band wiring is recommended. Atrophic nonunion requires interposition with bone graft and osteosynthesis. Intramedullary screw fixation results in a shorter time to fracture union, reduced complication rates, and earlier return to preinjury activities compared with nonsurgical cast immobilization [186].

28.14.8 Complications

Increased translational displacement may lead to mechanical impingement or interdigital neuromas. This is especially significant when dealing with first and fifth metatarsal deviations, which can cause post-traumatic hallux valgus and bunionette deformities and resultant shoe-wear problems. Increased plantar flexion of the distal fragment may cause increased loads on that metatarsal and may result in an intractable plantar keratosis. Similarly, the dorsal apex may produce a painful corn or exostosis.

28.15 Metatarsophalangeal and Interphalangeal Instability/Dislocations

Acute ruptures of interphalangeal ligaments, capsules, and the related plantar plate, especially with additional fractures of the sesamoids, may occur in severe forefoot trauma in athletes. These injuries may lead to significant problems if not recognized and/or treated adequately.

28.15.1 Organ-Related Disease: Definition of the Disease

The Jahss classification [187] of first metatarsophalangeal joint dislocations is dependent on the injury of the sesamoids and the intersesamoid ligament:

- Type I: plantar plate ruptures at its proximal attachment to metatarsal neck and dislocates with attached sesamoids riding over metatarsal head, sesamoids, and intersesamoid ligament are intact

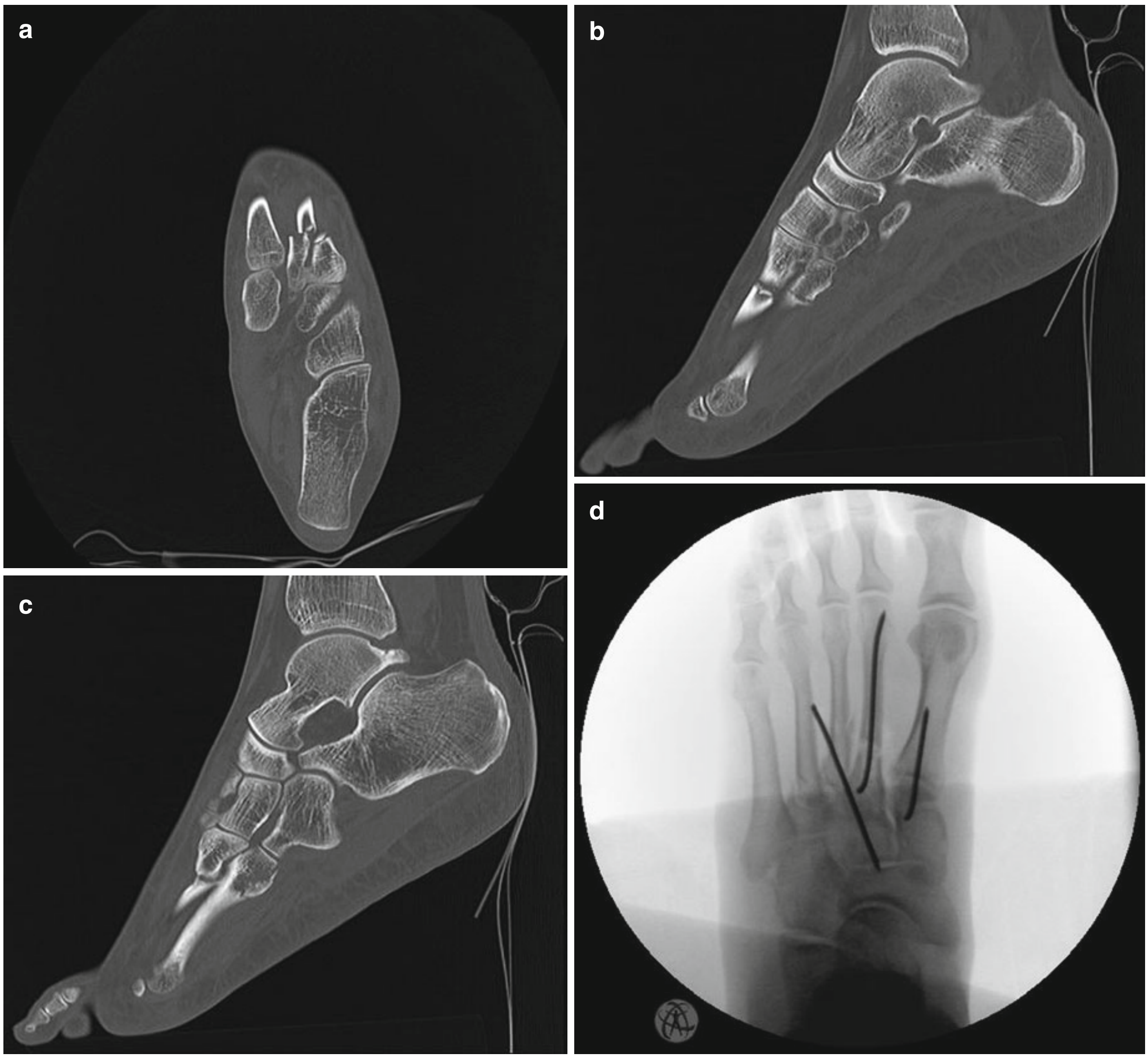

Fig. 28.31 Fractures of the second to fourth metatarsal base without dislocation at the tarsometatarsal joints and ligamentous instability of the first tarsometatarsal joint (**a**–**c**). Open reduction and retrograde transfixation of the third tarsometatarsal joint and antegrade intramedullary stabilization of the second metatarsal fracture as well as retrograde tarsometatarsal transfixation of the first TM-joint (**d**–**f**). The K-wires are removed at 8 weeks after bony and ligamentous healing (**g**)

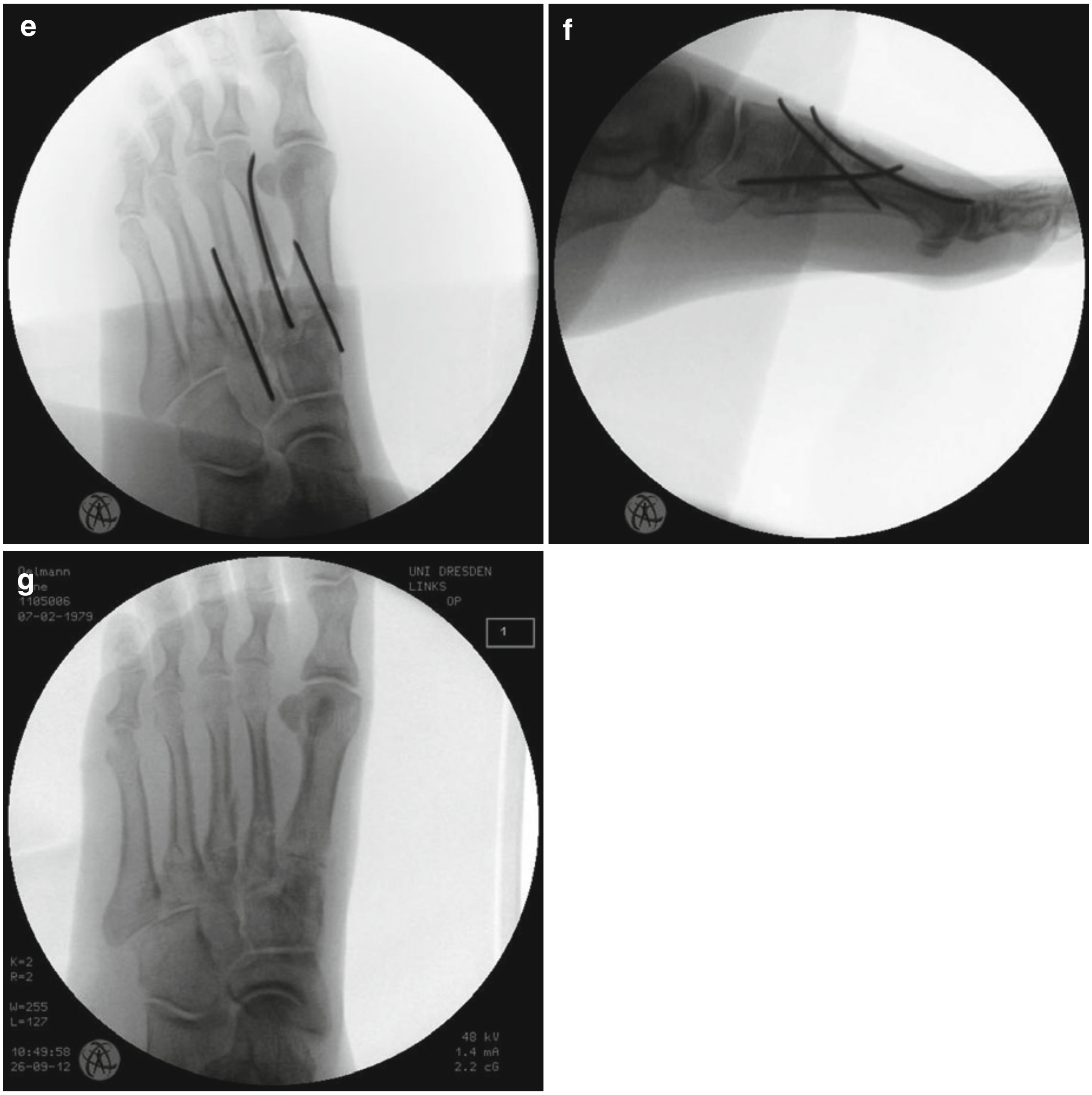

Fig. 28.31 (continued)

- Type IIa: widening of intersesamoid interval as a result of rupture of the intersesamoid ligament
- Type IIb: fracture of the sesamoids
- Type IIc: fracture of the sesamoid and rupture of the intersesamoid ligament

A type III has been added by Bousselmame and colleagues [188]:

- Type IIIa: complete soft tissue disruption of the plantar complex from the proximal phalanx
- Type IIIb: complete plantar plate disruption including disruption of one sesamoid

Two forms of irreducible dislocations of the interphalangeal joint of the great toe have been described by Miki and colleagues [189]. In type I, the ruptured volar plate with the sesamoid is displaced into the joint space between the two phalanges. In type II, the fibrocartilaginous-sesamoid complex is dorsally dislocated over the neck of the first metatarsal similar to that of a buttonhole deformity.

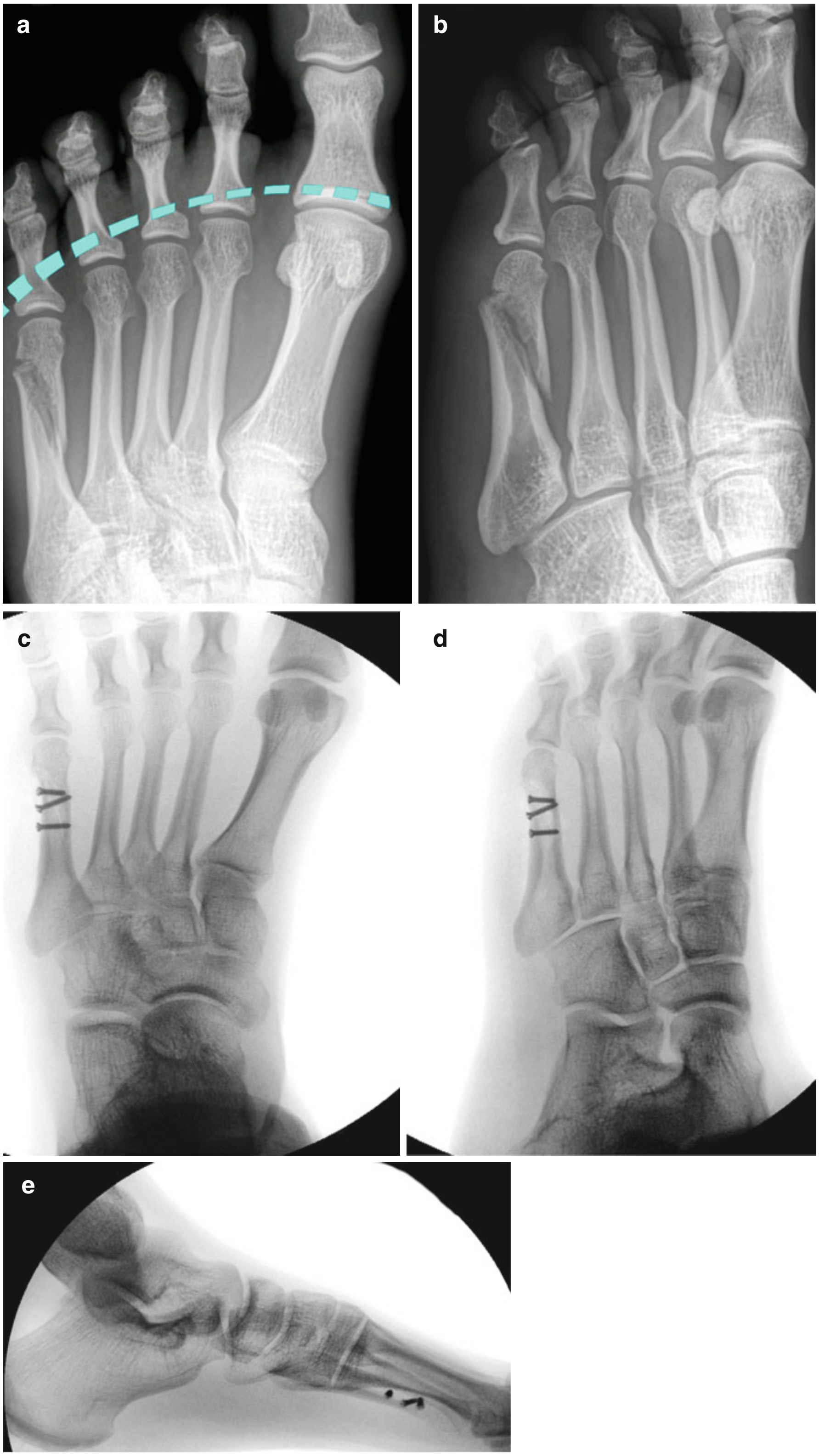

Fig. 28.32 A spiral shaft fracture of the fifth metatarsal is shown in the dorsoplantar (**a**) and oblique (**b**) views. Due to dislocation, shortening, and rotation of the fracture, open reduction and mini-screw osteosynthesis were performed (**c**–**e**)

Fig. 28.33 A dislocated shaft fracture of the fifth metatarsal occurred as the result of a fall after missing a stair (**a**, **b**). Because of the smaller distal fragment, open reduction, interfragmentary compression screw, and plate osteosynthesis were performed (**c**, **d**)

28.15.2 Epidemiology/Etiology

Metatarsophalangeal joint sprain commonly occurs at the first metatarsophalangeal joint. It is caused by sporting or car accidents through axial force acting on the dorsiflexed great toe (e.g., "turf toe") [190] or injury of the joint capsule of the metatarsophalangeal joint without dislocation (e.g., en-pointe position of ballet dancers) [191]. Complete instability causes dorsal dislocation of the phalanx, because of the weak dorsal capsule. Metatarsophalangeal instability of the second, third, fourth, and fifth rays can cause dislocation of the metatarsals head between the lumbrical muscles, making closed reduction difficult. At the interphalangeal joints, the medial collateral ligament can fold inwards with dislocation. Plantar and lateral subluxations are very rare [192].

28.15.3 Symptoms

Dorsal malposition of the phalanges is observed, with tension of the local soft tissue. The skin of the toes is pale plantarly and retracted dorsally. If the sesamoid is interposed in the joint space, the great toe appears longer [189].

28.15.4 Diagnosis: Recommended European Standard Diagnostic Steps of Investigation

Anteroposterior, lateral, and 45° oblique views of the forefoot should be obtained. Subluxations can be well seen in the lateral view. The rare plantar dislocation is subtle and difficult to diagnose.

28.15.5 Therapy

28.15.5.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

Dorsal metatarsophalangeal and interphalangeal dislocations should be reduced promptly (Fig. 28.34). Closed reduction takes place with forced plantar flexion under longitudinal traction with simultaneous plantar to dorsal pressure on the proximal fragment [180]. Early functional treatment includes taping or rigid-soled shoes for 3 weeks [180].

28.15.6 Surgery: Recommended European Standard Surgical Procedures

Two types of situations will make closed reduction difficult: interposition of the sesamoids (type I) or plantar plate (type II) in the joint space. The dorsal approach is recommended, because the plantar approach is associated with a risk of damaging the neurovascular bundle and can cause scar contraction. The intersesamoidal ligament is explored and the fractured sesamoids should be reduced. Resection of the sesamoids is not recommended as it can cause biomechanical imbalance. Complete instability with a tendency to redislocation occurs rarely. In such cases, temporary K-wire fixation for 3–4 weeks is indicated.

28.15.7 Complications

Overlooked subluxations of the second to fifth toes manifest with persistent pain over the heads of the metatarsals and claw toes [193]. Intramedullary screw fixation results in a shorter time to fracture union, reduced complication rates, and earlier return to pre-injury activities compared with nonsurgical cast immobilization [186]. In some cases, decreased range of motion at the metatarsophalangeal joint can occur and can be associated with hallux rigidus or sesamoiditis.

28.16 Reconstruction of the Metatarsals and Toes

Functionally most important is the reconstruction of the first and fifth metatarsal due to length, axis and positioning of the head within one plane of all five. Malunited plantar tilted metatarsal heads may cause significant pain during weigh tbearing. In complex forefoot trauma, saving of the big toe is important in relation to balanced gait and push off.

28.16.1 Organ-Related Disease: Definition of the Disease

Torg and colleagues [194] defined three types of fractures at the proximal shaft of the fifth metatarsal according to their healing potential:

- Type 1: acute fractures
- Type 2: delayed union, with widening of the fracture line and evidence of intramedullary sclerosis
- Type 3: nonunion with complete obliteration of the medullary canal by sclerotic bone

28.16.2 Epidemiology/Etiology

Mild post-traumatic axial deviation of the metatarsals and phalanges are often incidental and asymptomatic. Malposition in the horizontal plane is well tolerated. However, malposition in the sagittal plane, particularly at the metatarsal heads, can cause mechanical metatarsalgia [56].

28.16.3 Symptoms

Descent of the second, third, and fourth rays as well as ascent of the first and fifth rays should be corrected.

28.16.4 Radiology

Radiological investigation includes dorsoplantar, lateral, and oblique views of the forefoot as well as weight-bearing views of the metatarsal heads. Pedography demonstrates plantar pressures. Descent of the second, third, and fourth rays as well as ascent of the first and fifth rays should be corrected. X-rays should be performed with the foot in a plantigrade position.

28.16.5 Therapy

28.16.5.1 Surgery: Recommended European Standard Surgical Procedures

Correction of the lowered metatarsal head is performed with a subcapital oblique osteotomy, so-called Reikeras osteotomy [195] (Fig. 28.35). Functional postoperative management allows full weight-bearing in a customized shoe. The elevated metatarsal

Fig. 28.34 Dislocation of the fifth metatarsophalangeal joint and an undisplaced fracture of the third metatarsal head (*blue arrow* in **a**, **b**). The dislocation was closed reduced and taped. Because of the undisplaced metatarsal head fracture (*white arrow* in **b**), an additional Lopresti-Slipper was applied (**c**, **d**)

Fig. 28.34 (continued)

head is corrected via a plantar flexion closing-wedge osteotomy.

Horizontal malposition of the metatarsals should only be corrected if the biomechanics of the foot is affected, (e.g., metatarsus primus varus, subcapital axial deviation of the metatarsals with subluxation in the metatarsophalangeal joint, hallux valgus or digitus quintus varus, claw toes, or hammer toes) [56]. Claw toes or hammer toes are often the sequela of a compartment syndrome.

28.17 Fractures of the Toe

Significantly displaced intra-articular fractures, especially of the base of one of the toes or of the proximal interphalangeal joint of the big toe, need open reduction and fixation like other fractures of the lower leg to prevent painful post-traumatic arthritis.

28.17.1 Epidemiology/Etiology

Fractures of the phalanges are the most common injury of the forefoot. The mechanism of injury ranges from low-energy trauma due to indirect forces, to high-energy trauma and a direct impaction force following a fall. One of the common fractures is the so-called "night-walker" fracture, which involves the proximal phalanx of the fifth toe [196] (Fig. 28.35). The proximal phalanx of the hallux is also commonly fractured [197]. Comminuted fractures or displaced fractures through the lesser toes most commonly occur at the proximal phalanx as it is the longest of the phalanges.

Injuries to the lesser toes are often overlooked or dismissed as "sprains." Phalangeal fractures usually result in plantar apex angulation secondary to the combined effect of the extensor mechanism and intrinsic muscles. Stress fractures of the distal phalanx of the first toe have been described. Hallux valgus predisposes to stress fractures of the proximal phalanx of the great toe [198]. The systematics of the AO/ICI classification also apply for toe fractures, as described above [16].

Fractures in the sesamoids may occur by direct trauma or by repetitive overuse as a stress fracture or during fracture dislocations of the first metatarsophalangeal joint (Fig. 28.42). Progressive traumatic hyperextension of the first metatarsophalangeal joint leads to a lesion of the plantar capsule at the metatarsal neck, this attachment being weaker than the attachment at the proximal phalanx.

28.17.2 Symptoms

Symptoms include pain in the forefoot, swelling, hematoma, and tenderness of the involved digit, and an associated ecchymosis are quite common.

28.17.3 Diagnosis

28.17.3.1 Recommended European Standard Diagnostic Steps of Investigation

Physical examination reveals localized tenderness and swelling in addition to pain and crepitus with motion

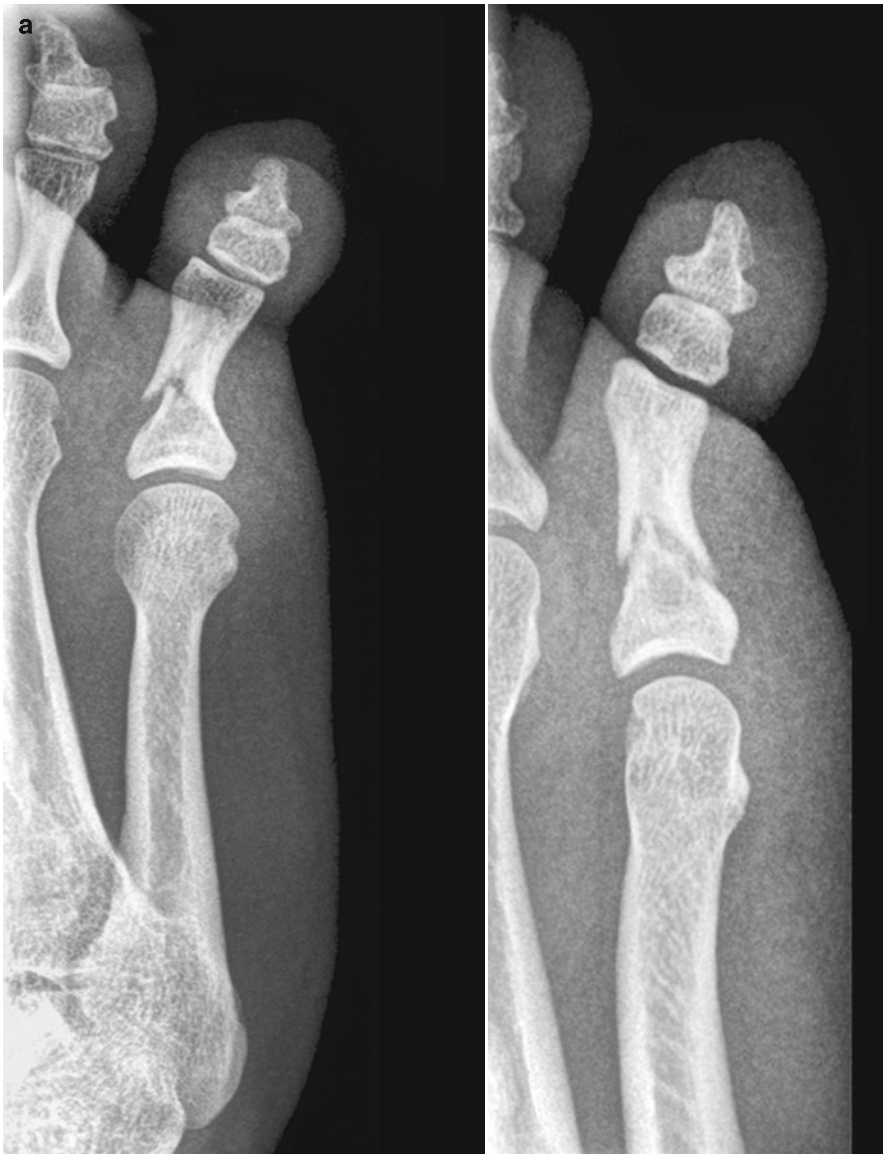

Fig. 28.35 A fracture of the proximal phalanx of the fifth toe (**a**) can be closed reduced and taped (**b**)

Fig. 28.35 (continued)

of the toe. Subungual hematoma is a hallmark of distal phalangeal fractures. Many injuries are secondary to direct trauma or crush injury, and careful examination of the soft tissue and neurovascular status should be performed.

Dorsoplantar and oblique (45°) radiographics of the forefoot are standard. Cone-down views can also be informative. The lateral view is often noninformative, because of overlapping, but can be useful to see the direction of dislocation.

28.17.3.2 Additional Useful Diagnostic Procedures

Bilateral radiographs can be helpful for discriminating between traumatic and nontraumatic issues. Focused images are indicated if the injury is well confined or for follow-up reasons. An axial or skyline view of the sesamoids should be performed in those cases where a pathological condition of the sesamoids is suspected. Fluoroscopy is helpful in purely ligamentous injuries, where stress testing can demonstrate the degree of instability that might not be apparent in standard static X-ray views.

Stress views of the sesamoids can visualize displacement of the sesamoid complex with dorsiflexion of the great toe, which gives an indirect hint at a rupture of the plantar plate if distal migration of the sesamoids with dorsiflexion does not occur. In chronic problems, weight-bearing X-rays of both feet usually clearly depict the site of the deformity or instability.

28.17.4 Therapy

28.17.4.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

Undisplaced fractures could undergo early functional treatment by taping to the adjacent toe (buddy taping) for 2 or 3 weeks and protected mobilization in a rigid-soled shoe with a wide toe box (Fig. 28.35). The interdigital space should be padded, to avoid maceration of the skin. The majority of patients with sesamoid fracture can be treated nonsurgically by protection, rest, ice, compression and elevation (acronym "PRICE).

28.17.5 Additional Useful Therapeutic Options

28.17.5.1 Recommended European Standard Surgical Procedures

Subungual hematomas are trephined under sterile conditions. Fractures associated with injury of the nail bed must be treated like open fractures. This involves debridement, lavage, and temporary K-wire transfixation.

Displaced fractures require closed reduction and taping under regional anesthesia. If reduction proves to be unstable, consideration should be given to percutaneous pinning. If the fracture is not amenable to closed reduction or if it demonstrates significant articular step-off, then open reduction and internal fixation with two crossed K-wires or mini-screws may be appropriate (Fig. 28.36). This is often necessary at the big toe. Bicondylar fractures of the great toe need stabilization with a mini-fragment plate [199].

Post-operative immobilization in a Lopresti slipper with a hallux extension is recommended for 10 days. The patient is allowed full weight bearing [4].

Stress fractures of the sesamoids occur more commonly in the tibial sesamoid. If pain persists after stress fractures of the sesamoids, the resection of the tibial sesamoid via a plantar medial approach is recommended [181].

Careful protection of the medial neurovascular bundle and removal of the sesamoid without disrupting the flexor brevis tendon or lacerating or dividing the flexor hallucis longus can prevent the development of a hallux valgus [200]. Excision of both sesamoids should, whenever possible, be avoided [201].

28.17.5.2 Additional Useful Surgical Procedures

In amputation injuries, conservation of the stump of the proximal phalanx will be helpful for providing a buttress for the adjacent toes to prevent horizontal instability and secondary deformity.

28.17.6 Differential Diagnosis

Stress fractures of the sesamoids may create differential diagnostic problems, as with sesamoiditis, osteochondritis dissecans, avascular necrosis, adventitious bursitis and tenosynovitis of the flexor hallucis longus, chondromalacia, osteochondritis, localized plantar keratosis, and impingement of the medial plantar digital nerve. Progressive activity-related pain and swelling underneath the first metatarsal head will lead to the correct working diagnosis.

28.17.7 Prognosis

Fractures of the toes generally have a good prognosis [181].

28.17.8 Complications

Trauma may be overlooked if it is not perceived by patients with systemic metabolic disease (e.g., diabetes

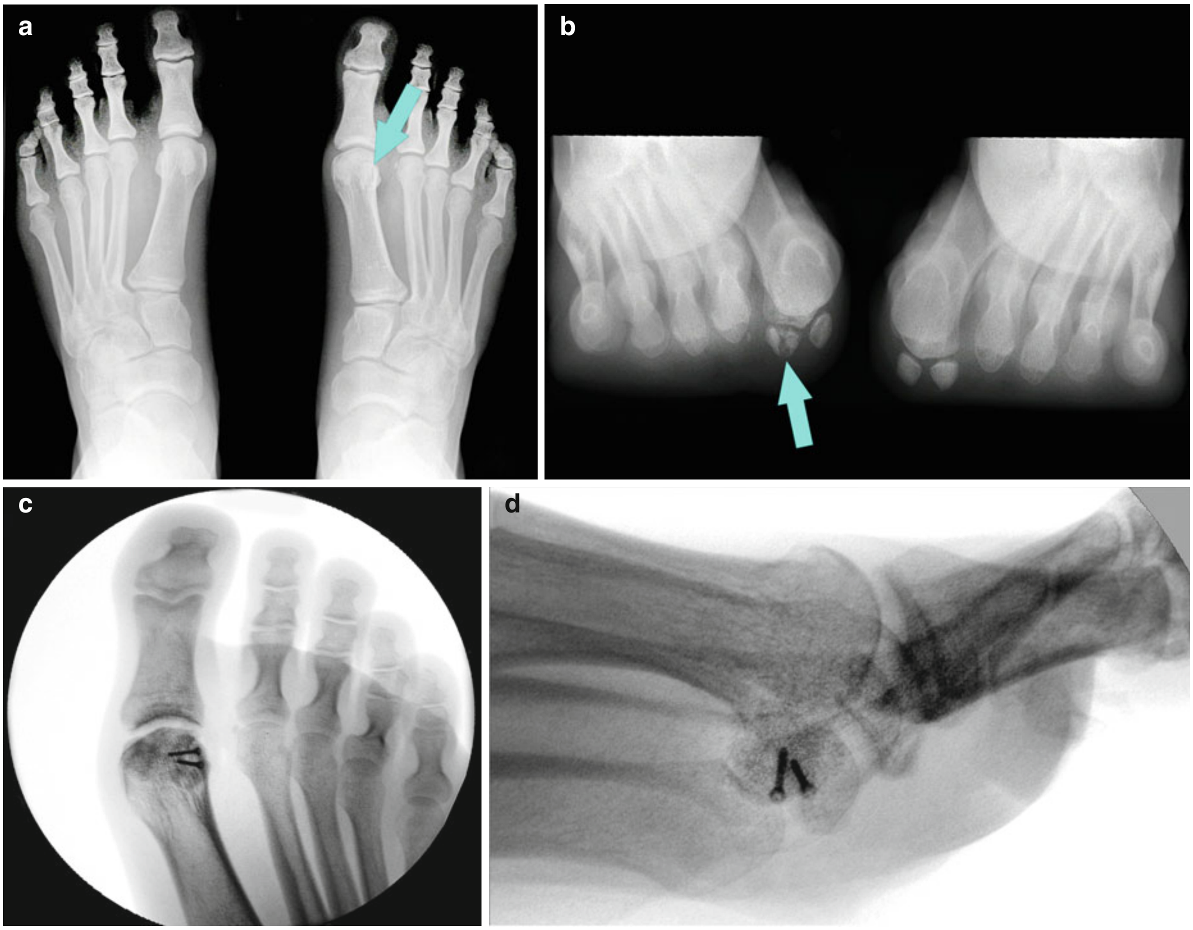

Fig. 28.36 This patient suffered from a fracture of the lateral (fibular) sesamoid after a strong jump during a volleyball game. Initial X-ray analysis did not show a fracture. Because of persistent pain, follow-up X-rays were performed 4 months later, where a delayed union of the lateral sesamoid was confirmed in the dorsoplantar (*arrow* in **a**) and the skyline view of the sesamoids (*arrow* in **b**). Surgery was performed with resection of the nonunion, interposition of cancellous bone, taken from the medial malleolus, and osteosynthesis with two mini-screws (**c**, **d**)

mellitus), or neurological disorders leading to peripheral somatosensory deficits. The diagnosis might be rendered more difficult if the initial clinical presentation of trauma is minimally symptomatic as in some physeal injuries of the distal phalanx of a stubbed toe in children, where subungual bleeding may be the only hint of an open injury and later sequelae such as osteomyelitis and growth arrest may develop. Inadequate management of nail-bed trauma may lead to nail deformity, malalignment, splitting, or chronic infection.

Malunion of toe fractures can cause disability due to subsequent interdigital corns. Intra-articular fractures can cause severe post-traumatic arthritis and limitation of movement resulting in hallux rigidus of the first ray.

28.18 Achilles Tendon Rupture

Hippokrates (460–375 bc) was the first to describe a lethal fever if the "Neura megala" the Achilles tendon became infected. Avicenna (980–1037 AD) named it "Chorda magna Hippocratis," and Vesalius (1514–1564 AD) as "Tendo latus." Heister (1683–1758 AD) spoke first about the "Tendo achillis." It is interesting to know that up until the year 1929 only 68 Achilles tendon ruptures were reported in the whole worldwide literature.

28.18.1 Anatomy

The Achilles tendon is the strongest tendon of the human body. It receives contributions from both the gastrocnemius and soleus muscles. The gastrocnemius is composed of a lateral head and larger medial head, which arise from facets above their respective femoral condyles. The soleus originates from the oblique line of the tibia and the middle one-third and the upper one-third of the fibula. The aponeuroses of both muscles combine to form the Achilles tendon, which is 10–15 cm in the length and inserts into the middle one-third of the posterior surface of the calcaneus. Two bursae exist. The retrocalcaneal bursa lies between the tendon and the superior portion of the calcaneus, and the second one lies superficial to the tendon below the skin near its insertion. The Achilles tendon is surrounded by a paratenon that helps to vascularize the tendon. As the tendon descends towards its insertion, the orientation of the fibers rotates 90° so that the lateral fibers end up superficial while the medial fibers become deep.

28.18.2 Physiology/Pathophysiology

Breaking strength is greater than 400 kp.

28.18.3 Epidemiology/Etiology

Degeneration is an important factor in the development of a closed tendon rupture. Recreational athletes with sedentary occupations are particularly at risk. Predisposition: local or systemic introduction of corticosteroids, rheumatic disease. Twenty-percent have inflammatory changes like tendinitis before rupture. Incidence: ratio of men to women 5:1 [202]. Ninety percent of all ruptures are in the middle third of the tendon. Acute Achilles tendon ruptures occur through direct and indirect mechanisms of injury. Direct injuries are less common than indirect and can be either closed or open injuries. The tendon usually is under mild tension when a direct blow results in rupture (e.g., jumping or pushing off). Open injuries are the result of sharp lacerations or severe open crush-type injuries.

28.18.4 Symptoms

The patient may recall a pop or snap that may or may not be audible after jumping, pushing off, or landing after a jump. This is associated with sudden pain in the calf posterior to the ankle. Patients present with pain, weakness, ecchymosis, swelling, or difficulty walking. If the tendon has preexisting severe degeneration, there might be only a little pain at the point of rupture. There is an inability to plantar flex against force, for example, standing on tiptoe.

28.18.5 Organ-Specific Radiology

Ultrasound confirms the diagnosis and helps in the decision making as to whether operative or conservative therapy is required. Advantages of ultrasound are fast availability, low cost, and dynamic examination. Chronic degenerative or inflammatory features can be documented. Signs of rupture include discontinuity with unrestricted movement of the tendon stumps and enlargement of the intact tendon parts with loosening up of the striped echo in comparison with the intact or uninjured side. A lateral view of the calcaneus can pick up bony avulsions or preexisiting calcification in the tendon.

MRI is useful in the diagnosis of chronic ruptures. It has the ability to demonstrate the extent of damage an partial tears and can also identify areas of intrasubstance degeneration that are not palpable clinically.

28.18.6 Diagnosis: Recommended European Standard Diagnostic Steps of Investigation

Inspection of the injured calf will reveal edema and ecchymosis. On palpation, a defect in the tendon, a “hatchet strike defect,” can be appreciated. The most reliable test used in the diagnosis of Achilles tendon rupture is the Thompson’s test. The patient lies in the prone position on the examination table either with the feet hanging over the edge of the table or the knees bent at 90°. The calf is squeezed just distal to its maximum circumference. A positive test results in no observable plantar flexion and indicates a complete rupture of the Achilles tendon.

Less than 30 % adaptation at the rupture in the horizontal plane with respect to the total diameter during ultrasound investigation indicates operative therapy. Between 30 and 70 % adaptation, the decision will depend on patient factors, which means co-morbidity or pre-morbid function.

Contraindications include local or systemic risk factors (e.g., decompensated diabetes mellitus) and immunodeficiency; because of deep infections, necrosis can result.

28.18.7 Therapy

28.18.7.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

Immobilization in a long leg cast in 20°–30° ankle equinus for 8 weeks, followed by a 2.5-cm heel lift for further 4 weeks is not recommended, because the risk of re-rupture is 5–25 % [202]. After immobilization in a below-the knee-plaster for 3 days, functional treatment in a specially designed shoe with full weight-bearing is recommended. The shoe with a 3.0-cm lifted heel allows immobilization at the ankle as well as protection against torsion. The shoe is worn for 6–8 weeks, day and night, and for an additional 2 weeks during the day.

An important part of the functional-conservative treatment is regular ultrasound assessment, which determines the duration that the special shoe is worn and the reduction of heel lift. Diastasis can be diagnosed and operated on early.

Physiotherapy starts after 3–4 weeks with isometric force exercises, isokinetic ergometer training, proprioceptive neuromuscular fasciculation, and electro- and cryotherapy. Stepwise decrease of the heel lift starts at the 6th week. After taking off the shoe, physiotherapy is continued. Sports are allowed 13–16 weeks after initial injury [202]. Wearing a 1.0-cm heel lift for 6 months is recommended.

28.18.8 Surgery: Recommended European Standard Surgical Procedures

Surgery should ideally be performed in the first week after rupture. Numerous open procedures have been described in the literature, including simple end-to-end suture, plantaris weave reinforcement, peroneus brevis reinforcement, fascial augmentation, and pull-out wire techniques (e.g. Marlex) [203].

The most common open procedure is the classical suture from Bunnell and Kessler, often used in hand surgery. Percutaneous suture techniques reduce wound edge necrosis and protect the peritenon (peritendineum) [204]. Radical debridement with partial or total excision of the Achilles tendon is required for deep infection. Local or free flaps are used for skin defects. Long defects of the Achilles tendon are treated with pedicled transplants (e.g., flexor hallucis longus, posterior tibial tendon, or peroneus brevis tendon), or augmentation with the gastrocnemius fascia or synthetics (e.g., Marlex, Dexon).

28.18.9 Prognosis

There is an incidence of 5–25 % of re-ruptures with conservative immobilization therapy.

28.18.10 Complications

Twelve percent experience wound edge necrosis. Lesions of the sural nerve are reported after percutaneous suture. There is an incidence of 1.4–1.8 % re-ruptures after operative therapy, 5–25 % after conservative immobilization therapy, and 2–3 % after conservative functional therapy [130, 205]. Deep infection occurs in 2 % of all cases [206].

28.18.11 Exemplary Surgical Procedures

28.18.11.1 Percutaneous Suture Technique

Suture of the Achilles tendon with a special instrument, a so-called Dresdner instrument, via a 2–3-cm incision proximal to the rupture, without opening the peritenon or the rupture site. The suture in the area of the proximal Achilles tendon is placed in the layer between the lower-leg fascia and the peritenon, with the threads running in a paratendinous direction [207] (Fig. 28.37). A change is made to a conventional suture technique if there is insufficient suture hold. Postoperative management is functional. After operation, the special shoe can be removed for daily foot care. Physiotherapy commences 1 week after surgery.

Re-rupture

The ruptured tendon ends should be freshened, and adequate tendon diameter allows simple secondary suture. Deficient tendon will require reconstruction with the fascia of the gastrocnemius or augmentation with the long plantar tendon or synthetics, as well as tendon replacement with the flexor hallucis longus

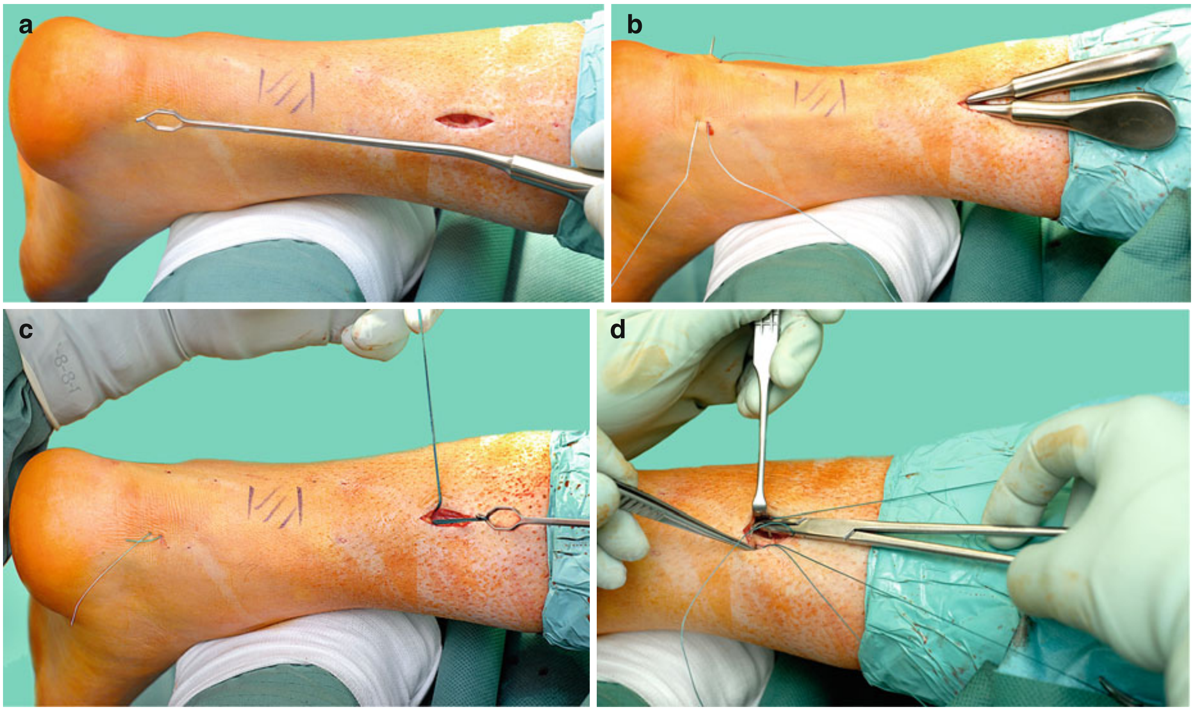

Fig. 28.37 After laying out the instrument to plan later positioning, the rupture site and the skin incision are marked. A 3-cm longitudinal, dorsomedial incision is made at a distance of at least 2 cm from the rupture site (**a**). The lower-leg fascia is prepared and opened. The instrument aperture is positioned approximately 1 cm proximal to the insertion of the Achilles tendon at the calcaneus. A straight needle is used to pierce through the skin, the aperture of the instrument, and the Achilles tendon (**b**). The suture ends are pulled out at the incision (**c**). The proximal anchorage of the sutures is ensured by a suture from lateral or medial toward the central tendon part, while the assistant holds the foot in maximum plantar flexion and the knot is tied and firmly tightened (**d**)

tendon or the fascia lata [208, 209]. Dynamic long flexor hallucis replacement is recommended [208, 209].

28.19 Complex Trauma and Amputation of the Foot

Treatment of complex foot trauma is a substantial challenge to any trauma surgeon's skills. Complex foot trauma is often combined with polytrauma. In elderly patients involved in car accidents, it is like a "signum mortis," being part of the whole.

28.19.1 Anatomy

The plantar sole of the foot is divided into three compartments. The lateral compartment contains the abductor digiti minimi and the short flexor and opponens muscle of the fifth toe. The medial compartment contains the abductor hallucis, flexor hallucis longus, and brevis muscles. The central compartment has a superficial portion that contains the flexor digitorum brevis, a deeper intermediate portion that contains the quadratus plantae, and the proximal portion of the flexor digitorum longus. This compartment directly communicates with the lower calcaneal chamber, which leads into the tarsal tunnel and proximally into the posterior compartment of the leg.

28.19.2 Organ-Related Disease: Definition of the Disease

The definition of complex foot trauma depends on the regional extent (one point of every injured foot plane) as well as the degree of the soft tissue damage (Tscherne and Oestern classification, 0–4 points) [87]. Following are the planes of the foot:

First plane: pilon and ankle
Second plane: talus
Third plane: calcaneus

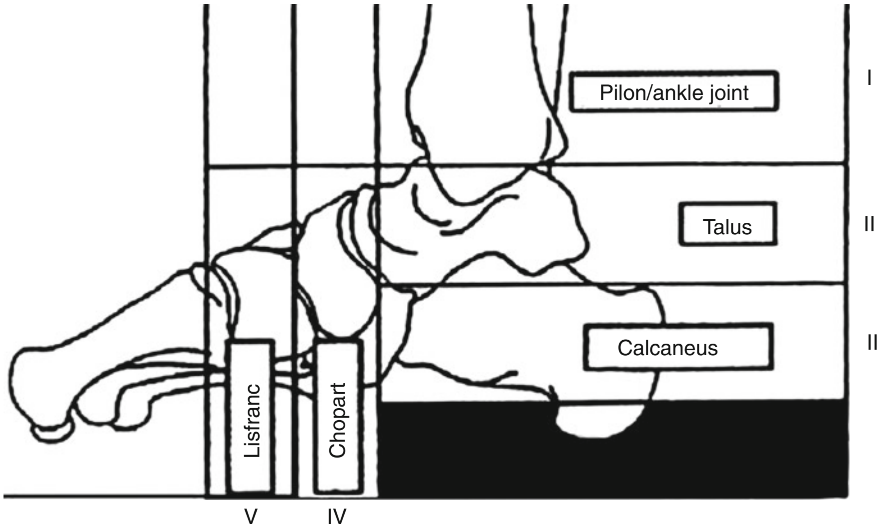

Fig. 28.38 Classification of complex foot trauma according to Zwipp [4]. One point is given for each affected functional-anatomical region as well as for the degree of soft tissue damage. A complex foot trauma is defined as 5 or more points

Fourth plane: Chopart

Fifth plane: Lisfranc (Fig. 28.38)

A complex foot trauma is defined as five or more points [4].

28.19.3 Epidemiology/Etiology/Principles

The decision regarding the primary attempt at reconstruction or amputation depends on the degree of accompanying injuries. Tscherne recommends primary reconstruction with 1 point of the polytrauma key (PTS, Hannoveraner Polytraumaschlüssel) and primary amputation with a PTS of 3 and 4 points [210]. Life has priority before limb.

Other scoring systems for the evaluation of the severity of foot injuries are the Mangled Extremity Severity Score (MESS) and the NISSSA score (Nerve injury, Ischemia, Soft tissue injury, Skeletal injury, Shock and Age of patients), the PSI (Predictive Salvage Index), and the LSI (Leg Symptom Index).

Extensive loss of plantar soft tissue is more severe than loss of dorsal tissue, as these injuries cannot be easily reconstructed with tissue of similar type. Injuries to the main blood vessels affect the viability of the distal foot as well as the anastomosis of free flaps. Loss of protective foot sensation on the plantar aspect of the foot, caused by a traumatic lesion of the tibial nerve, is associated with an increased risk of late soft tissue complications.

Primary arthrodesis, indicated by severe bone fragmentation and unsalvageable joints, can result in a rigid foot. This can cause increased unphysiological pressure on the compromised soft tissue. Pantalar arthrodesis, caused by loss of the talus or its joint surfaces, results in a rigid foot with severe functional impairment.

28.19.4 Diagnosis

For a foot with a partial amputation (Fig. 28.39) to function optimally, the following criteria must be met: (1) the weight-bearing areas must be covered with healthy skin that is as adapted as possible for weight-bearing; (2) as much length as possible should be preserved in the foot insofar as it is compatible with; (3) if the forefoot is shortened through amputation, the dorsiflexion and plantar flexion musculature must be rebalanced to compensate for the shorter lever arm acting against the triceps surae; (4) if the amputation is performed at the level of Lisfranc joint or higher, disrupted inversion and eversion musculature should be reestablished and rebalanced.

28.19.5 Therapy

28.19.5.1 Nonoperative Treatment: Recommended European Standard Therapeutic Steps

Patient education and adaptive training can prevent morbidity and identify problems before they become

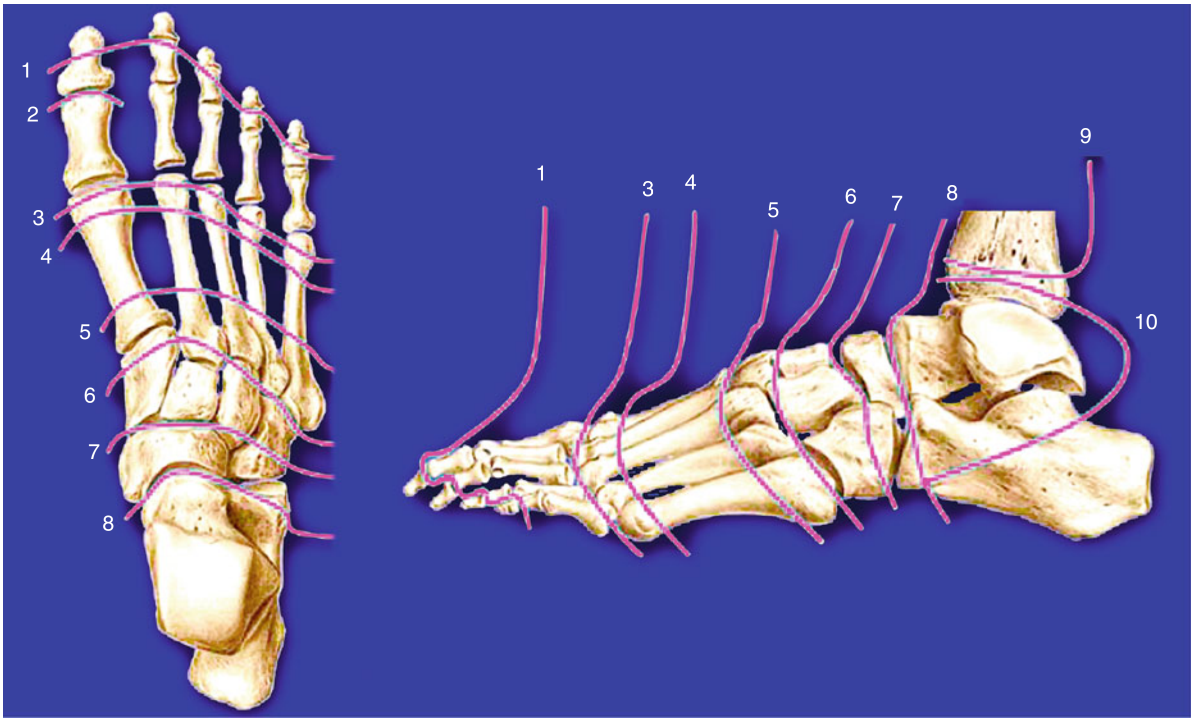

Fig. 28.39 *Amputation lines: 1* distal phalanx amputation, *2* partial big toe amputation, *3* exarticulation at the metatarsophalangeal joint, *4* distal extended exarticulation at the metatarsophalangeal joint, *5* proximal transmetatarsal amputation (Sharp), *6* Lisfranc amputation, *7* Bona-Jäger amputation, *8* Chopart amputation, *9* Syme amputation, *10* Pirogoff/Spitzy amputation

insurmountable. Localized foot and nail care serve to prevent infection or tissue breakdown. Prophylactic and therapeutic inlay extra depth shoes with pressure and shear-dissipating orthotics are prescribed for patients at risk. The biologic amputation level is the most distal functional amputation level that can support wound healing. Determined by clinical examination, the following may be performed: measurement of vascular inflow by ultrasound Doppler, tissue nutrition as measured by serum albumin, and immunocompetence as measured by total lymphocyte count.

28.19.6 Surgery: Recommended European Standard Surgical Procedures

Complex foot trauma is a surgical emergency. Good evaluation of the vitality of the skin, muscles and bone is achieved by avoiding the use of a tourniquet. Debridement, jet lavage, and resection of nonvital structures are necessary. Signs of muscle vitality include color, bleeding, contractility, and consistency, which influence the decision as to whether amputation or reconstruction should be performed. A second-look operation after 48–72 h is recommended [4]. Primary reconstruction requires an open or closed reduction and minimally invasive osteosynthesis with K-wires or screws, in combination with tibio-metatarsal external fixation.

Open fractures require antibiotic prophylaxis with second-generation cephalosporins [211]. Early definitive wound closure within 72 h reduces infection rates [106]. The type of wound closure or coverage depends on defect size, location, and exposed structures.

28.19.7 Prognosis

If the three indices of wound healing, vascular inflow, tissue nutrition, and immunocompetence, are adequate, amputation wound healing rates of over 90 % can be expected.

28.19.8 Complications

Complications are postoperative residual limb edema, poor quality skin or adherence of the skin to the underlying bone, and phantom limb sensation with the feeling that all or part of an amputated limb is present.

28.19.9 Exemplary Surgical Procedures

28.19.9.1 Compartment Syndrome of the Foot

Lisfranc fracture dislocations often cause disruption of the intrinsic foot muscles, resulting in a pathological pressure increase in the midfoot compartments. Calcaneus fractures result in compartment syndrome in 40 % of all cases. When there is a compartment syndrome of the lower leg, one should look for an accompanying compartment syndrome of the foot.

Fasciotomy is recommended at an absolute pressure of 25 mmHg, because the threshold for development of blisters and the ischemic threshold of intrinsic foot muscles as well as that of nerves and blood vessels are lower than in the lower leg. Fasciotomy can be carried out either through a single long midline incision or a two-incision technique. All foot compartments should be decompressed and the wounds left open.

28.19.9.2 Phalangeal and Metatarsophalangeal Amputation

Amputation of the second, third, and fourth toes leads to little loss of function. The threshold for reconstruction of the great toe should be lower, because of its important function during the gait. The great toe acts as a stabilizer of the foot during the terminal stance phase of gait. Distal phalanges are completely disarticulated to prevent flexion contractures. Middle phalanges are disarticulated at the joint or base, depending on the defect size. Proximal phalanges should be left as long as possible with refixation of the extensor aponeurosis. Tendons and nerves are shortened under slight traction and the residual condyle is rounded off. The nerves are pulled down gently, cut sharply and allowed to retract, and the blood vessels are cauterized. After complete toe disarticulation, the articular cartilage of the metatarsals provide a barrier to bacterial infection. After disarticulation of the first and fifth toes, the head of the metatarsal is beveled. If the base of the first phalanx must be sacrificed, the surgeon should disarticulate it, denude the distal and inferior cartilage, and re-attach the tendons of the flexor and extensor muscles to the capsule by means of tenodesis. Arthrodesis of the sesamoids in their correct position should be considered. Whenever possible, a long flap of viable plantar skin should be preserved and brought over the end of the forefoot to meet the shortened dorsal skin [4].

28.19.9.3 Transmetatarsal Amputation (Sharp)

The disarticulation level should be as distal as possible, as this can allow good function of the foot when it is performed correctly. The plantar flap should be long. It requires smooth plantar beveling of the metatarsals and the first toe should be slightly shorter than the second; the rest should slope down gradually in length to the fifth. The most important functional consideration is to rebalance plantar flexion and dorsiflexion muscle strength.

This invariably requires at least a gastroc slide. Whether the posterior tibial muscle should be lengthened is decided on an individual basis. The extensor digitorum longus tendons may have to be inserted into the peroneus tertius or the lateral dorsal fascia, especially in the absence of the peroneus tertius on examination of the opposite side. The fifth extensor should be attached by means of tenodesis to the fascia at the base of the fifth metatarsal.

28.19.9.4 Tarsometatarsal Amputation (Lisfranc) and Mediotarsal Amputation (Chopart)

These classic amputations are used for severe destruction of the forefoot in an emergency. There is a high risk for development of a flexion contracture, which is why it should be combined with tendon rebalancing. During Lisfranc disarticulation, the extensor tendons are cut in foot dorsiflexion and fixed on the cuneiforms and cuboid [212]. For the Chopart disarticulation [137], the stirrup-like fixation is at the talus with the anterior tibial and peroneus longus tendon, allowing an active elevation of the talus [213]. With secondary equinus contracture, a corrective arthrodesis of the ankle or hindfoot may be needed [4]. An alternative is the transtarsal amputation of Bona-Jäger between the navicular and the cuneiforms, preserving the proximal cuboid.

28.19.9.5 Transcalcaneal Amputation [214]

Transcalcaneal amputation [214] is indicated with severe foot destruction as well as in neuropathic Charcot feet. Stable amputation with a loadable heel pad is recommended, which provides a barrier for ascending infection. The advantage is the possibility of radical resection of devitalized muscles and tendons. A leg length difference of approximately 1 cm results. After Chopart disarticulation, the tendons and muscles are shortened. The talus is disarticulated. The cartilage of the malleoli is resected completely.

Osteotomy of the anterior calcaneal process is approximately 1 cm proximal to the Chopart joint and includes shortening of the sustentaculum tali [4]. The calcaneus is inclined 70–80° and fitted in the ankle mortise. Osteosynthesis is performed with two 6.5-mm cancellous screws from distal to proximal. Skin defects can be skin grafted. Postoperatively, an elastic prosthesis shoe with a plastic laminate socket and a rocker bottom sole may be worn. With this modified Pirogoff technique, only about 2.5 cm of limb shortening will result [213].

28.19.9.6 Ankle Disarticulation [215]

The original amputation according to Syme [215] is a pure disarticulation at the ankle joint, while retaining the heel skin. This amputation type is often used in older patients with vascular disease or in severe foot destruction as an alternative to the lower-leg amputation.

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29 Pediatric Fractures and Dislocations

Christoph Nau, Dorien Schneidmüller, and Ingo Marzi

29.1 Introduction

Different fracture patterns and problems in diagnosis and therapeutic management in children are related to differences in anatomy, physiology, and biomechanics in comparison to adults. The aim of this chapter is to provide an overview of general principles in trauma to the immature skeleton, diagnostic and treatment concepts, and frequent complications. Furthermore, common and complex injuries are described in detail.

29.2 Epidemiology of Fractures in Children

Pediatric trauma represents 13–32 % of all registered injuries. Fractures make up 10–25 % of all injuries of entire population. Fracture incidence has increased with wider participation in sports and more sports-related injuries. Ninety percent of all fractures are located at the extremities, whereas fractures of the trunk only constitute 10 % and therefore are not considered in this chapter. The risk of sustaining a fracture increases with age approximately until age 13. The overall annual incidence is about 21–25 fractures per 1,000 children. Boys have a 1.2–1.6 higher risk of sustaining a fracture than girls. Whereas in younger children the proportion is nearly balanced, after the age of eight boys are disproportionately more often involved in accidents than girls. Fractures of the long bone in the upper extremity are observed two to three times more often than fractures in the lower extremity. The main localization is the metaphysis, with 65 %, followed by the diaphysis, with 25 %. Injuries of the epiphysis are rarer, with a rate of 10 %. The predominant fracture is that of the distal forearm, which constitutes nearly 25 % of all fractures, followed by fractures of the hand. Considering only the long bones, the most common injury is the fracture of the distal radius (40 %), followed by fractures of the distal humerus (16 %), the tibial shaft (10 %), and the distal tibia (9 %) (Fig. 29.1).

Statistically significant focuses are observed in three constellations. Firstly, fractures of the distal humerus in infants are mainly caused by playground accidents or at home. Secondly, fractures of the lower leg in older children and adolescents are associated with a high rate of traffic accidents. And thirdly, fractures of the distal forearm in all age groups are caused by sports-related traumas.

29.3 Post-traumatic Growth Disorders and Remodeling

The body is able to compensate remaining post-traumatic deformities to a certain extent by epiphyseal and periosteal correction mechanisms. The amount of

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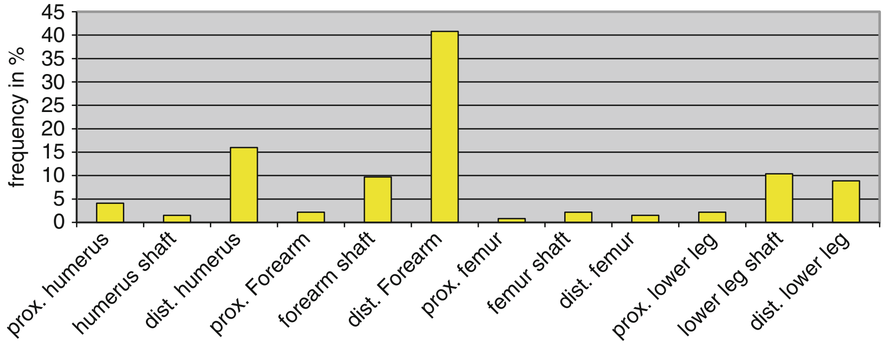


Fig. 29.1 Distribution of fracture frequency of fractures of the long bones in children ($n=678$) (Taken from: Kindertraumatologie Marzi; Publisher: Steinkopff)

the correction potential depends on the age of the child, the growth reserves of the corresponding physis, the location and direction of the dislocation, and the necessary correction direction. The periosteal correction is predominantly responsible for the correction of the ad latus displacement. Axis kinking in the diaphysis can also be compensated through periosteal correction mechanisms, because the concave side of the compression stimulates the bone regeneration, whereas bone is resorbed at the opposite convex side (Fig. 29.4). Simultaneously, the adjoint transversal standing physis adjusts orthogradely to the stress axis. Contractions can be compensated to a certain extent by growth stimulation within the fracture healing. A specific length adjustment is only possible in bone pairs such as the forearm. Rotation dislocations or post-traumatic elongations cannot be compensated or, if so, only poorly.

Elongations of the particular extremity must be expected because of corresponding growth stimulation that depends on the necessary remodeling. No functional consequences result at the upper extremity, so the spontaneous correction should be considered in the therapeutic strategies. At the lower extremity, larger dislocations should not be left to spontaneous correction to avoid leg distance differences with influence on the whole anatomical structure; thus, anatomic reposition should be the goal.

29.3.1 Growth Disorders

Stimulating and inhibiting growth disorders can be differentiated. Each fracture of a long bone leads to an excessive growth. The degree depends on the age of the child, the dislocation, the amount and the time of the reposition attempts, and the degree of the necessary remodeling. This leads to an elongation of the specific extremity, which is only relevant for the lower extremity concerning the biomechanical or anatomical structure of the spine. Therefore, regular clinical controls are necessary up to 2 years after the trauma. Partial growth stimulation is uncommon. It only plays a role in fractures of the proximal tibia with resulting increasing valgus or in condyle radial fractures with resulting increasing varus.

Injuries to the physis, directly or indirectly by vessel lesions, can cause early physis closure. A full closure leads to a shortening of the corresponding extremity. Growth disorders with increasing deformity of the axis are caused by incomplete closures. The degree depends on the age and the maturity of the child, the skeleton's location, the proximity to the physis, and the degree of the dislocation. The occurrence of growth disorders cannot be avoided specifically. Ideal conditions, provided by correct anatomic reposition and avoidance of iatrogenic physis injuries, can only affect the appearance of growth disorders positively. In addition to clinical controls of the axis and length proportions in side comparison, an X-ray dense line, called the Harris line, which usually runs parallel to the physis, can provide a hint of partial growth disorders.

29.4 Characteristics of Injuries to the Immature Skeleton

29.4.1 Fracture Pattern

The specialties of the child's skeleton with the physis, the strong ligaments, and the thick periost as well as the high elasticity of the bone leads to a stereotypic fracture pattern differing from that of adults. Therefore, special fracture forms exist for the child:

Bulge fracture: This fracture occurs in the area of the metaphysis, where the bone offers the highest porosity. It can be found in young children and it is called a stable and uncomplicated fracture. Usually, a therapeutic and short immobilization is sufficient for pain relief.

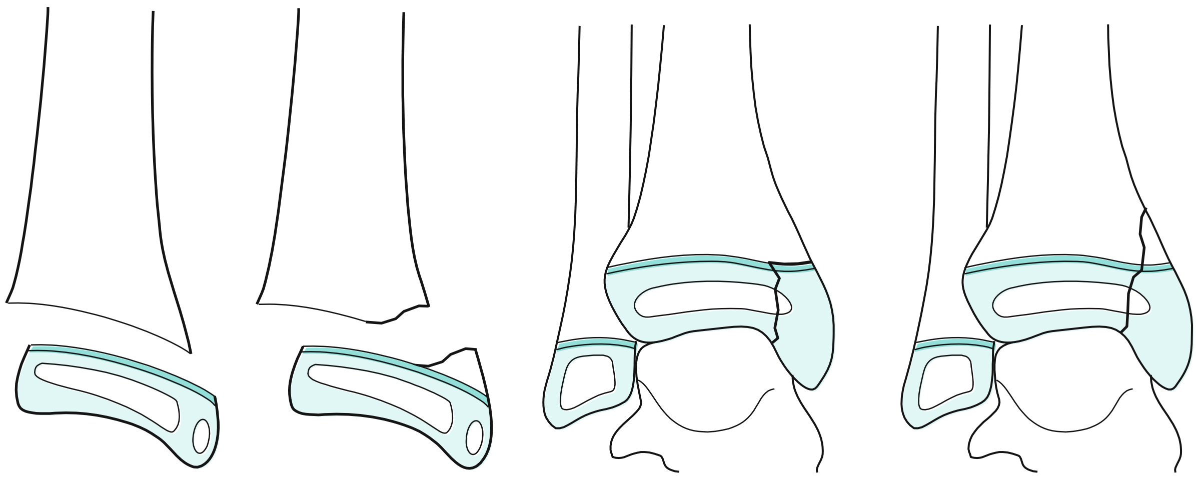


Fig. 29.2 Classification of the growth plate fractures according to Salter und Harris: Salter–Harris I: loosening of the growth plate; Salter–Harris II: growth plate loosening with metaphyseal wedge; Salter–Harris III: epiphyseal fracture; Salter–Harris IV: epiphyseal fracture with metaphyseal participation (Taken from: Kindertraumatologie Marzi; Publisher: Steinkopff)

Bowing fracture: Because of the high elasticity of the child's bone, a deformity occurs without a visible fracture. It can be apportioned functionally to the greenstick fractures.

Greenstick fractures: As a result of bowing, at the border of elasticity a greenstick fracture occurs. The trauma's energy is not sufficient to break the bone completely. It is characterized by a full fracture of the side with the application of the force with intact opposite cortical. Because of the faster fracture healing and callus building of the opposite side, the danger of refracture exists in the diaphysis if fracture healing is absent in the area of the fracture gap.

Stress fractures: At the beginning of walking, an unused stress can cause an overload reaction of the child's bones (toddler's fracture). It mostly occurs at the tibia, the fibula, and the tarsal bones and cannot usually be seen in the first X-rays but impresses in the course by callus building.

29.5 Fracture Classification According to Salter and Harris (Figs. 29.2 and 29.17)

Salter and Harris I: This refers to epiphysiolysis, usually as a result of shear injuries. If the periosteum remains intact, these fractures can appear almost undislocated and may be hardly recognizable radiologically. Clinically, local pressure pain and swelling are present solely over the concerned growth joint.

Salter and Harris II: If torsion forces also appear, a metaphysis wedge can break out next to the physis loosening, which is also called a Thurston-Holland fragment. An open reduction can become necessary in the affected periosteum.

Salter and Harris III: Here, the fracture line passes through the epiphysis into the joint.

Salter and Harris IV: The fracture passes through metaphysis and epiphysis.

Salter and Harris V: This describes an injury of the growth joint, caused by axial compression, without primary lesions visible in the X-ray. It presents primarily as a bruise or distortion and appears over the course of time as a growth disorder.

During adolescence, there is a slow closure of the physis, which leads to a changed fracture course. These fractures are generalized under the term "transitional fractures." This fracture is most often seen in the distal tibia, which is described in the following example. It can, however, also appear at other localizations (Fig. 29.3). The affecting power deflects to the joint by the already ossified part of the physis, so that a more or less large ventrolateral epiphyseal fragment results as an ossified syndesmosis rupture, a so-called "two-plane fracture," according to the size of the already resulting physis closure.

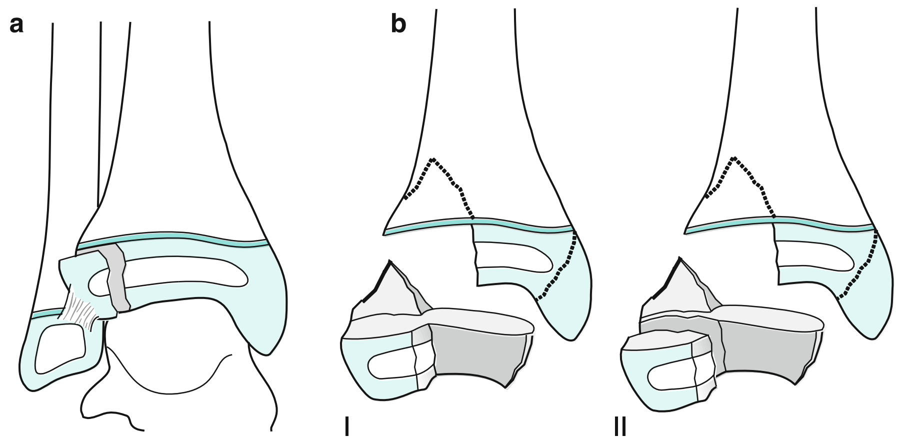


Fig. 29.3 Transition fractures of the distal tibia: (**a**) Two-plane fracture/Tilleaux fracture: epiphyseal fracture in already-beginning epiphyseal fusion; (**b**) Triplane fracture: epiphyseal fracture in already-beginning epiphyseal fusion with dorsal metaphyseal (triplane I) or epimetaphyseal wedge (triplane II) (Taken from: Kindertraumatologie Marzi; Publisher: Steinkopff)

Additional torsion powers can lead to a breakout of a dorsal additional fragment, corresponding to a Volkmann triangle, the so-called "tri-plane fracture." If the metaphyseal fracture line ends in the joints, we speak of a "tri-plane-I fracture"; if it runs through the meta- and epiphysis, it is a "tri-plane-II fracture." In comparison to fractures with a wide-open physis, the fracture lines often run obliquely. The Salter injury usually runs perpendicular to the physis, and mostly lies within the main burden of the joint zone. The fracture line of the Salter injury runs eccentrically far outside the stress-bearing area. Because of the low growth potential of these children, the reconstruction of the joint surface is the primary aim in these injuries, while relevant growth disorders are not to be expected at this age.

29.6 Diagnostics

29.6.1 Clinical Examination

The clinical investigation first covers the anamnesis, which identifies the localization of the injury, the energy of the trauma, and the relation of the trauma to possible child abuse or pathological fractures. After a thorough inspection, a careful palpation follows. Young patients should be informed about and provided with explanations of procedures. An examination of the peripheral blood circulation, motor function, and sensitivity should be performed in all cases. Expanded functional tests are mostly unnecessary because of lack of consequence in the acute stage and are potentially painful for the child.

29.6.2 Diagnostic Imaging

The X-ray diagnostics represent a special challenge. Radiation exposure should be minimized and all technical means should be used to reduce the radiation dose. Because of the large portion of X-ray-permeable cartilage tissue and the characteristics of the still-growing skeleton (e.g., the occurrence of ossification centers), good knowledge of age-dependent diagnostic findings is critical for the examiner. The frequently recommended comparative picture of the opposite side in the diagnosis of fresh injuries does not replace this knowledge and may be inefficient and unnecessary. If an operative indication is already provided by the first picture, a second plane can be avoided for the protection of the child. This can be accomplished under anesthesia. For all other fractures, the X-ray in two planes (anteroposterior, or a.p., and laterally) with illustration of the adjoining joint is standard. Injury-centered pictures should be aimed for and overview pictures in two planes should be avoided for the exact evaluation. In special cases such as transitional fractures, additional diagonal pictures are helpful. Due to the X-ray-permeable cartilage tissue, some injuries can only be recognized by an extension of the growth joint or a dislocation of the adjoining bone.

Sonography is available as a preserving procedure in the evaluation of X-ray-permeable structures such as tendons, ligaments, and non-ossificating skeleton portions. Fractures can also be diagnosed directly and indirectly by proof of a subperiosteal hematoma or an accompanying hemarthrosis.

Computed tomography, primarily as a multilayer CT, applies the diagnostics of the polytraumatized child as well as of complex fractures of the spine, the basin, or the foot root with the possibility of low-dose programs. MRI offers a large range of application possibilities. It allows the demonstration of nonossifying skeleton parts, soft tissues, ligaments, and musculature. It is used in the diagnosis of occult fractures, of spine injuries, and of post-traumatic complications of joint and physis injuries, such as the detection of growth disturbances, osteonecrosis, or cartilage flakes. The missing radiation exposure is a further advantage. However, it is still an expensive diagnostic and requires long investigation periods, and often requires sedation or anesthesia in small children.

Other imaging procedures such as scintigraphy, angiography, or arthrography are not applied in routine diagnostics and are reserved for special indications.

29.7 Treatment Options

The aim of therapy is to achieve fast fracture healing without the occurrence of complications, taking into account socioeconomic aspects. Special needs and wishes can be considered with the knowledge of the growth prognosis and complication possibilities. This is mainly relevant for the shaft; the closer the fracture is located to the joint, the greater the extent that the therapy is determined by the fracture. Adequate pain therapy should always be part of the primary therapy. Therefore, it may be necessary to perform splinting for immobilization and/or medicinal pain therapy before making a diagnosis.

29.7.1 Nonsurgical Treatment

In most cases, injuries of the child can be treated adequately by conservative techniques. Usually, an immobilization (e.g., with a cast) is sufficient. At certain localizations, the immobilization in small children takes place with special bandages (e.g., Desault's bandage at the proximal humerus, the backpack bandage at the clavicle, or the fist bandage at the phalanxes). At certain localizations, secondary dislocations can be prevented and easy malpositions can be corrected by reduction bandages such as cast wedging, extension treatment, or the Cuff 'n collar.

29.7.1.1 Cast Wedging

Axis deviations in the frontal and sagittal plane of the shaft zone can be corrected by cast wedging in a circular cast. This is primarily indicated in distal forearm fractures and tibia shaft fractures with a malposition in the frontal and/or sagittal plane. It is usually performed 8 days after primary cast immobilization. The primary swelling should have decreased by that point so that a secondary dislocation is not to be expected. A relative stability is given by the already-generated callus, which reduces the pain, with, however, still-existing plastic deformability, so as to accomplish a correction of the malposition.

29.7.1.2 Extension

The extension therapy in form of a strip extension only plays a role in the treatment of femur shaft fractures in infants. Disadvantages are the usually long stationary stay as well as the missing possibility to control the position of the fracture during the therapy. Other extension measures (e.g., “the hanging cast”) in the treatment of the humerus fracture no longer belong among the proven therapy methods.

29.7.1.3 Cuff ’n Collar (Blount Sling)

This provides a dynamic redress of a slightly in extension dislocated humerus fracture. By the adjustment of a bandage that gradually brings the elbow into the swelling-conditioned maximum pointed angle position, it leads to a slow correction of the malposition.

29.7.2 Surgical Treatment

All completely dislocated or unstable fractures that cannot be turned into a stable fracture by closed reduction are an indication for operative therapy. The aim is to achieve a stable situation to avoid further reductions or changes in therapy. A movement and charge stability should be achieved if possible. Furthermore, factors such as effort (e.g., secondary removal of metal), costs, available resources, and personal experience play a role in the choice of the osteosynthesis method.

29.7.2.1 Reduction

Dislocations that will not be corrected in the course of the spontaneous correction should be reduced. In order to avoid unnecessary pain and fear, this should be performed under general anesthesia and in operation standby in order to be able to proceed openly in case of reduction barriers and to be able to perform a stable osteosynthesis if there is danger of redislocation. A primarily open reduction should be performed in any joint fractures with a dislocation >2 mm, defect fractures, and partial open fractures. Generally, the first reduction should also be the last and final. In fractures of the phalanxes with significant dislocation, a reduction with local anesthesia can be performed.

29.7.3 Surgical Treatment Concepts

29.7.3.1 Kirschner Wire Osteosynthesis

This is indicated in metaphyseal fractures, including epiphysiolysis of the long tube bones, as well as in hand and foot fractures. In small children or in small fracture fragments, it can also be used in epiphyseal fractures. It can be placed minimally invasively, percutaneously, and the metal removal can usually be performed ambulatory without anesthesia. However, an additional cast immobilization is necessary for the protection of the stability.

29.7.3.2 Screw Osteosynthesis

This is especially indicated in joint fractures, inasmuch as a compression of the fracture gap can be caused, but also in epiphysiolysis with metaphyseal wedge. In principle, it is movement-stable, nevertheless, an additional protective immobilization with a cast is necessary. It can be used minimally invasively by closed reduction and by an open procedure. Therefore, cannulated, self-cutting cancellous bone screws are particularly suitable.

29.7.3.3 Tension Banding Osteosynthesis

This is indicated anywhere strong muscle or ligament originates. It can only be placed by an open procedure. Examples include patella transverse fracture, fracture of the olecranon, and lateral fracture of the clavicle.

29.7.3.4 Elastic Stable Intramedullary Nailing (ESIN)

This is a minimally invasive, movement and partially load-stable procedure in the treatment of dia- and metaphyseal shaft fractures. It's basis is a three-point support of two inserted pretwisted flex, titanium nails within a tube bone which are inserted in opposite directions. The ideal fracture is a diaphyseal transverse fracture, but diagonal and spiral fractures can also be supplied by ESIN under adherence to basic biomechanical principles.

29.7.3.5 External Fixation

After ESIN, the external fixation represents the second most frequent method for the treatment of shaft fractures. It is mainly indicated in unstable long diagonal or multi-fragment fractures as well as in expanded tissue damage and for the fast treatment of the polytraumatized child.

29.7.3.6 Intramedullary Nailing

This is indicated in all tube bones with joints that have already been closed or with beginning joint closure, or in obese children. There is danger of damaging the physis directly or indirectly by damaging the supplying vessels (proximal femur) if the physis are still open. The procedure corresponds to the adult traumatology.

29.7.3.7 Plate Osteosynthesis

Plate osteosynthesis has been increasingly replaced by alternative methods like the ESIN in the treatment of shaft fractures. Usually, an open procedure with a large amount of tissue damage and cosmetically impairing scar formation is necessary. It remains subject to individual special indications like fractures of the phalanxes, of the hand and the foot, calcaneus fractures, and re-fractures of femur and tibia.

29.8 Special Fractures Types, Anatomical Distinctions

29.8.1 Clavicle

Clavicle fractures, accounting for 5–15 % of all fractures, children and adults, belong to the most frequent fractures in the infancy, mostly below the 10th year of life. They usually appear as birth trauma fracture or by direct impact. The fracture is often undislocated in infants because of the thick periosteal tube and leads to a fast fracture healing. Fractures are differentiated into the medial, middle, and lateral third; those in the middle third which occur most often. The therapy usually can be performed conservatively by immobilization in a cotton bandage or by backpack bandage. Consolidation control with still-open growth joints is done clinically by pressure indolent fracture callus and normalization

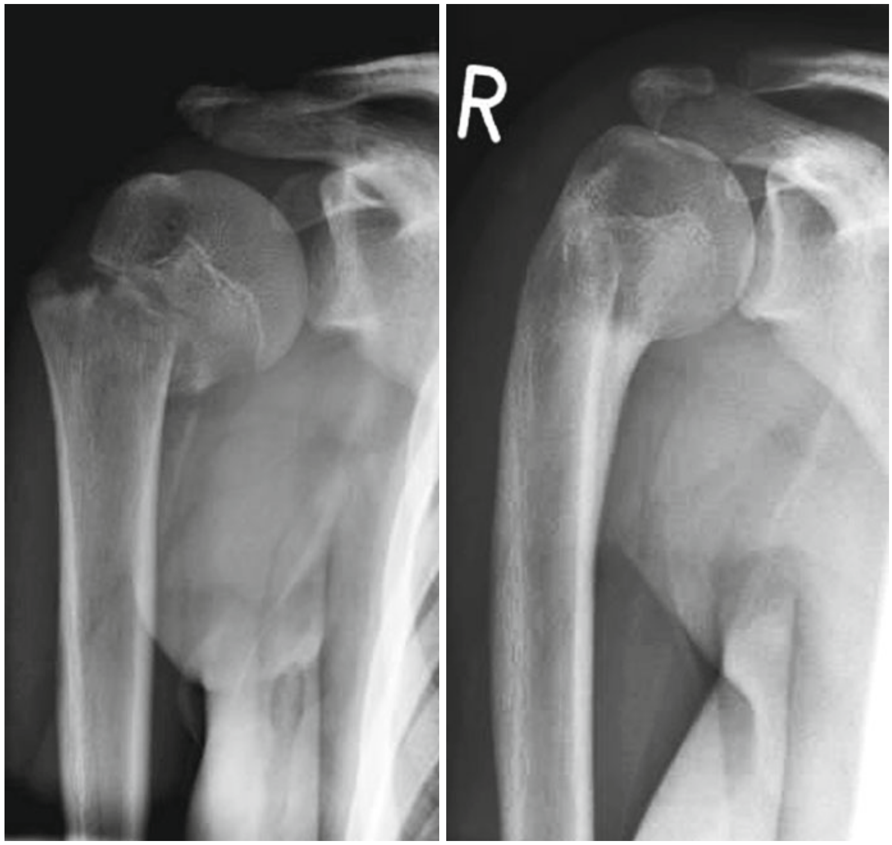


Fig. 29.4 Subcapital humerus fracture with spontaneous consolidation after 3 months

of the function after approximately 3 weeks. Radiological position control is not necessary in that case. Shortenings or side-to-side malpositions will usually be corrected by the reduction within a year. In adolescents, the extent of the spontaneous correction is not sufficient for a complete remodeling. Pronounced malpositions and shortenings should be avoided in this case. In some cases, the danger of skin perforation exists; here, open reduction and osteosynthesis should be accomplished. In addition to the well-known method of plate osteosynthesis, intramedullary splinting by ESIN is a possible alternative.

29.8.2 Upper Extremity

29.8.2.1 Humerus

Proximal Humerus

In the majority of cases, fractures of the proximal humerus mostly concern subcapital fractures followed by epiphysiolysis, with or without a metaphyseal wedge (Fig. 29.4). Epiphyseal injuries are rare. The age peak is located between the 11th and 12th year. Because of the large growth potential of the proximal epiphysis joint, relatively large malpositions can be tolerated and left to spontaneous correction. Below the 10th year varus, anteversion and retroversion dislocation up to 50° and a valgus dislocation up to 10° serve as tolerance limits; in children older than 10 years, 20° and 10°, respectively. Conservative therapy with an immobilization in a Gilchrist or Desault bandage for 3–4 weeks is primary treatment. If the correction limits are exceeded, a reduction needs to be performed, usually in a closed manner. The first-choice osteosynthesis is the movement-stable retrograde ESIN nailing. Alternatively, a percutaneous K-wire osteosynthesis can be performed, which however, requires an additional immobilization, which is not always simple.

Diaphyseal Humerus

Upper arm shaft fractures usually arise in the context of a birth trauma or in adolescence. The remodeling potential of the humerus shaft fractures is clearly smaller than that of the proximal fractures. Nevertheless, malpositions can be adjusted because of the large functional compensation potential of the closely related shoulder joint. However, axis dislocations over 10° often lead to a cosmetic impairment, so that these should not be left. Side-to-side malpositions will easily be corrected, and shortenings up to 2 cm can be tolerated. The conservative therapy in all fractures within the correction limits is done by immobilization in a Gilchrist or a Desault bandage, followed, if necessary, by a Sarmiento brace. All other fractures can usually be reduced closed and stabilized by ESIN antegradely or retrogradely. As an alternative method, external fixation is available in multifragment fractures or expanded tissue damage. Birth trauma-related injuries also heal with complete remodeling, even with larger malpositions. In this case, pain therapy by an individually adapted bandage is used for several days.

29.8.3 Fractures of the Elbow

Fractures of the distal humerus are differentiated from those of the proximal lower arm in fractures of the elbow joint. In addition, there exist ligament injuries, luxations, and combination injuries. Especially at the elbow joint, imaging diagnostics represent a special challenge because of the multiplicity of bone cores atising at different times. Knowledge of age-related injury patterns and the physiological anatomy of the increasing elbow is essential for correct diagnosis and therapy.

29.8.3.1 Supracondylar Fracture

The supracondylar fracture of the humerus is the most frequent elbow injury in adolescence (Figs. 29.5 and 29.6). The diagnosis of completely dislocated fractures does not represent a problem. If fractures are slightly dislocated and the fracture gap is infracted, however, fractures can easily be missed. In this case, the so-called Rogers line represents a proven aid. It is an extension of the ventral humerus cortical, which should cut in the transition from the middle to the rear third of the capitulum because of the physiological tilting of the humeral capitulum. In the frequent extension fractures, the line is located further ventral; in the rare flexion fractures further dorsal. Because of the small growth potential of the distal growth joint of the humerus, the possibilities of spontaneous correction are limited. A certain remodeling can be expected up to the 7th year maximally. Beyond that point, persisting malpositions in the sagittal plane can lead to significant movement restrictions. Thus, an extension fracture healed completely in antecurvation leads to an inhibition of the flexion ability of the elbow joint. In addition, a rotation error always has to be looked for in the X-ray. This can be recognized by the so-called rotation spur and by the caliber leap between the proximal and distal fragment.

This rotation error is an important sign of an instability, so that the often post-traumatically observed cubital varus is usually a consequence of a left rotation error with following instability and tilting into the varus. As a classification of the fractures, which considers these therapeutic important criteria, the classification after Laer, which differentiates according to dislocation planes, proves valuable.

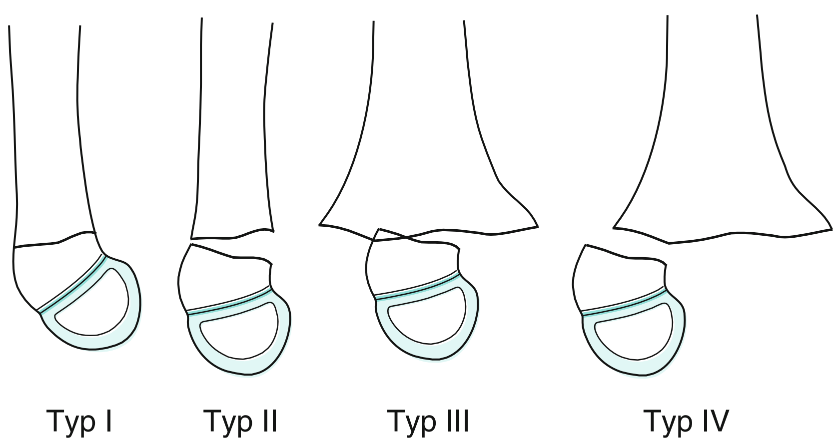


Fig. 29.5 Classification of the supracondylar fractures according to Lutz and Laer: Type I: no dislocation; Type II: dislocation in one plane (sagittal plane), Type III: dislocations in two planes, Type IV: dislocations in three planes (Taken from: Kindertraumatologie Marzi; Publisher: Steinkopff)

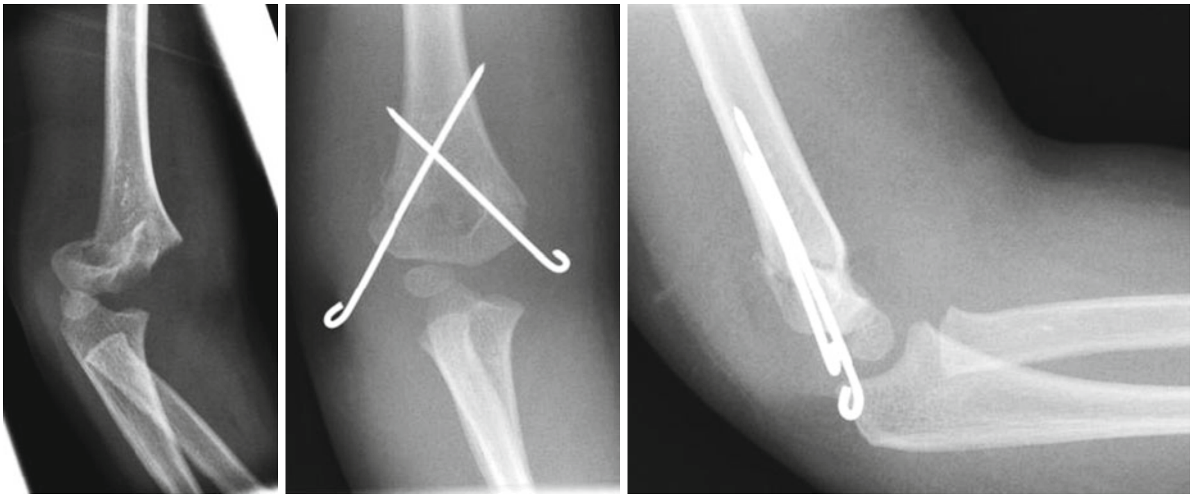


Fig. 29.6 Supracondylar humerus fracture (Type IV according to von Laer) and after K-wire osteosynthesis

29.8.3.2 Epicondylar Fracture

This fracture predominantly appears as a co-existing injury of a luxation of the elbow. Therefore, co-existing injuries have to be looked for if appropriate radiological findings are visible and the sideband stability also has to be controlled. Fractures with a dislocation up to 0.5 cm maximum can be treated conservatively; with larger dislocation and simultaneous luxation of the elbow, an operational revision is recommended. The refixation is usually effected by a preferably cannulated screw osteosynthesis. Growth disturbances are not to be expected, inasmuch as apophyseal injuries are involved. As a specific complication after conservative therapy, the development of a pseudarthosis has to be mentioned, which, however, only becomes symptomatic to a small extent.

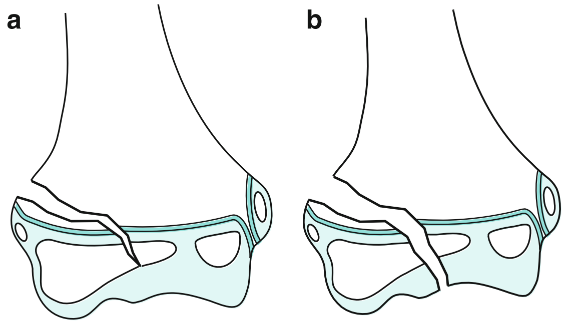


Fig. 29.7 Condyle radial fracture: the fracture is not completely shown in the X-ray because of the cartilage part of the capitulum. Incomplete stable (**a**) and complete instable (**b**) fractures must be differentiated (Taken from: Kindertraumatologie Marzi; Publisher: Steinkopff)

29.8.3.3 Transcondylar Fractures

The condyle radialis fractures exceed >90 % of all transcondylar fractures in contrast to condyle ulnar fractures, with an age peak at 4–5 years; whereas the much rarer condyle ulnar fractures and Y-fractures occur in adolescents. The difficulty of the condyle radialis fracture is in the evaluation of the dislocation, because of the predominantly cartilaginous constructed humeral trochlea.

The diagnosis of completely dislocated fractures is usually not difficult. Undislocated fractures have must be differentiated into the incomplete stable (cartilage hinge intact) and the complete unstable (articular surface disrupted) fractures with the danger of secondary dislocation. A safe primary distinction is possible (e.g., by sonography or MRI). An X-ray control of the undislocated fractures after 4–6 days without cast is approved in order to exclude a secondary dislocation. If a dislocation has not appeared up to that point, a stable injury can be assumed and a conservative therapy can be performed in an upper arm cast. All dislocated fractures have to be reduced open and the joint surface has to be reconstructed. If possible, a compression osteosynthesis should be accomplished by cannulated screws (Figs. 29.7 and 29.8). As a major complication, the stimulative growth disturbance is a factor next to remaining intra-articular stage formations. Their extent is predominantly dependant on the stability of the fracture supply. They can lead to radial growth stimulation

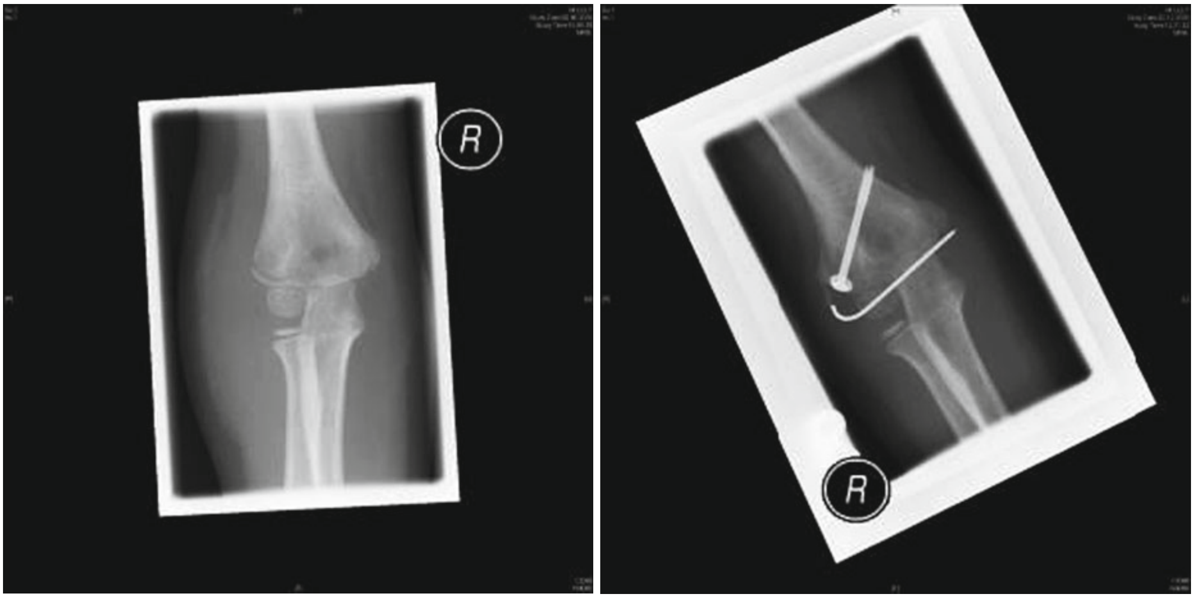


Fig. 29.8 Screw and K-wire compression osteosynthesis in a condyle radial fracture

with following varus position of the elbow axis in the radial condyle fractures and Y-fractures, and, in the condyle ulnar fractures, to a ulnar growth stimulation with following valgus position.

29.8.4 Proximal Forearm

29.8.4.1 Radial Neck Fracture

The actual epiphyseal radius head fracture is rare in the infancy. Mostly it concerns radius neck fractures, whereas it concerns metaphyseal fractures in approximately two-thirds of the cases, and epiphyseal solutions in one-third of the cases. It usually arises by a fall on the stretched arm or as an accompanied injury of a luxation of the elbow or in the context of a Monteggia injury. Because of a large correction potential, relatively large malpositions can be left. In children under 10 years old, a tilting of 45° is considered the limit, in older children it is 20°. A precondition is early functional therapy as soon as possible, so that the time of immobilization for pain therapy should be kept as short as possible (approx. 1–2 weeks). Because there is only the metaphyseal blood supply of the radius epiphysis, the danger of post-traumatic blood circulation disturbance with necrosis of the radius head exists. Dislocated fractures should be reduced closed so as not to endanger the blood circulation of the radius head and should be stabilized, if unstable, by ESIN.

29.8.4.2 Fracture of the Proximal Ulna

Intra- and extra articular fractures of the olecranon can be differentiated. Often, a combination injury with, for example, a radius neck fracture, radius head luxation in the sense of a Monteggia injury, or fractures of the distal humerus, present. Undislocated fractures can be treated conservatively in an upper arm cast for approximately 3–4 weeks. The traction powers of the M. triceps easily lead to a dislocation, which should be reduced open anatomically and be stabilized by tension band or screw osteosynthesis. Extra-articular fractures frequently present a varus malposition, which corrects itself poorly spontaneously in the further process and can lead to disturbances of the rotation.

29.8.4.3 Dislocation of the Radial Head/Monteggia Lesion

Isolated luxations of the radius head are extremely rare. Usually, an accompanying pathology of the ulna in context of a Monteggia injury is present, which can easily be missed if it concerns a bowing of the ulna. The classical Monteggia fracture concerns an ulna shaft fracture with a simultaneous luxation of the

Fig. 29.9 Monteggia lesion; the elongation of the proximal radial axis is not projected on the core of the capitulum

radius head. As a Monteggia-like lesion, we characterize functionally equivalent injuries in which the ulna can be fractured further proximal up to the olecranon. In addition, a luxation fracture of the radius head can occur in the context of the accident. Thus certain elements in the imaging diagnostics have to be considered. If an allegedly isolated radius head luxation is visible, an X-ray of the entire lower arm has to be made in order to exclude a fracture of the ulna shaft, especially a bowing injury. On the other side, in case of an isolated ulna fracture in the lower arm radiograph, an X-ray of the elbow has to be made to exclude a luxation of the radius head. The extension of the proximal radius axis must project itself on the core of the humeral capitulum in all planes (Figs. 29.9 and 29.10). When recognized early, the prognosis is good. By reposition of the ulna fracture, the radius head can be reduced easily. The retention of the ulna is either done by ESIN or alternatively in proximal fractures by plate osteosynthesis.

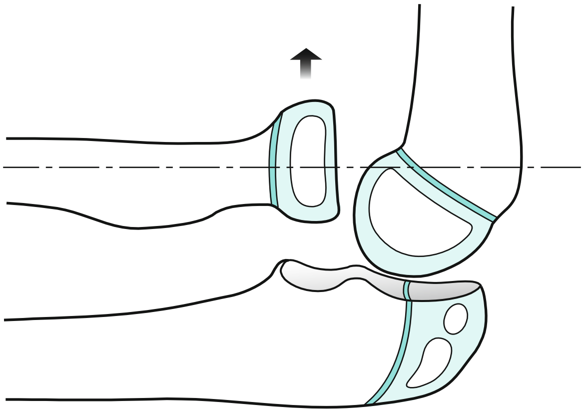


Fig. 29.10 Radial head luxation: the elongation of the proximal radial axis has to be projected on the core of the capitulum in all X-ray planes (Taken from: Kindertraumatologie Marzi; Publisher: Steinkopff)

The later the injury is recognized, the worse the prognosis will be. Significant malfunctions can result from extension and clumping of the radius head. Usually a complex conversion as well as an extension of the ulna is necessary, in order to bring back the radius head into its original position.

29.8.4.4 Nursemaid's Elbow/Chassiagnac Luxation/Subluxation of the Radial Head/Pronation Doloreuse

The pulled elbow syndrome is one of the most commonly presented injuries in the emergency room between the age of 1 and 4 in infants. After the age of 5 years, the attachment of the annular ligament to the neck of the radius strengthens and prevents displacement and radial head subluxation. Typically, a sudden pull at the arm is present in the anamnesis. Equally often, however, the accident mechanism is not known or a distortion or a fall on the elbow is described. The child preserves the arm in an easily inflected pronation position. With atypical anamnesis or an unsuccessful reduction approach, an X-ray in two planes should be performed to exclude an osseous injury. The reduction is done by longitudinal traction with slight pressure on the radial head and (alternatively) a pronation movement, or (instead of the pronation movement) a supination inflection movement or a supination extension movement. Typically a "click" can be noticed under the finger during the reduction of the head. A reduction does

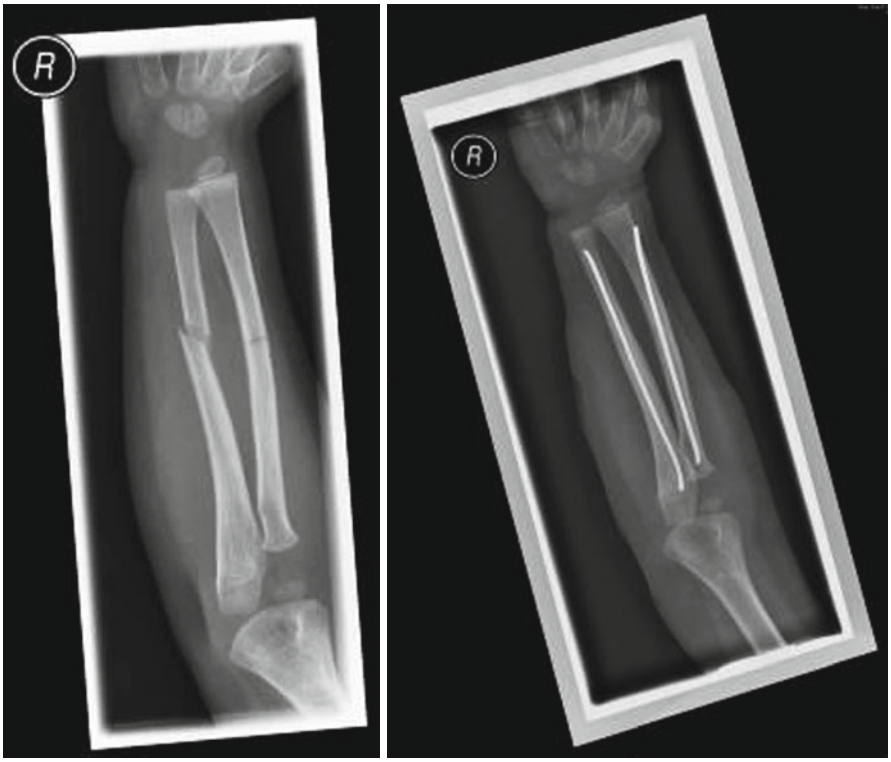


Fig. 29.11 Complete diaphyseal fracture of the forearm before and after ESIN stabilization

not always succeed at the beginning, so an upper arm cast should be applied after three reduction tries for 3 days. The function is often free after immobilization or a renewed reduction attempt can be effected.

29.8.5 Forearm

The therapy of the lower arm fracture is mainly depends on the type of the fracture and the localization. The main part concerns the distal third of the forearm, where frequently a conservative therapy can take place, whereas the spontaneous correction ability decreases clearly to the shaft center.

About two-thirds of the forearm fractures are greenstick fractures. In the shaft zone, there is danger of the retarded fracture healing with a high refracture rate along with restrictions of the turning movement because of left axis deviations. Therefore, no axis deviations should be accepted in the shaft zone, and greenstick fractures should be to break and transfer into complete fractures and stabilized afterwards. In the shaft zone, the intramedullary splinting by ESIN is the method of choice today (Fig. 29.11).

29.8.5.1 Distal Forearm

Fracture of the Distal Forearm

In contrast to the shaft center, the distal metaphyseal forearm is able to correct axis deviations up to 30°. Small malpositions can be corrected by cast wedging if necessary. In children over the 12 year of age, no malpositions should be left. Reduction should take place under general anesthesia in operation stand-by. If instability of a metaphyseal fracture can be seen as well as an epiphysiolysis, a percutaneous K-wire osteosynthesis is performed for stabilization (Fig. 29.12). Fractures at the transition of the distal to the middle shaft third are often not adequately supplied by K-wire osteosynthesis or intramedullary splinting, so that an external fixation should be placed. Bead fractures or greenstick fractures mainly occurring in infancy are considered to be stable and unproblematic. Here, a temporary immobilization in a forearm cast for 2–3 weeks until analgesia with pressure indolent callus is sufficient. Growth disturbances are rarely expected.

Fig. 29.12 Fracture of the distal radius and after K-Wire stabilization

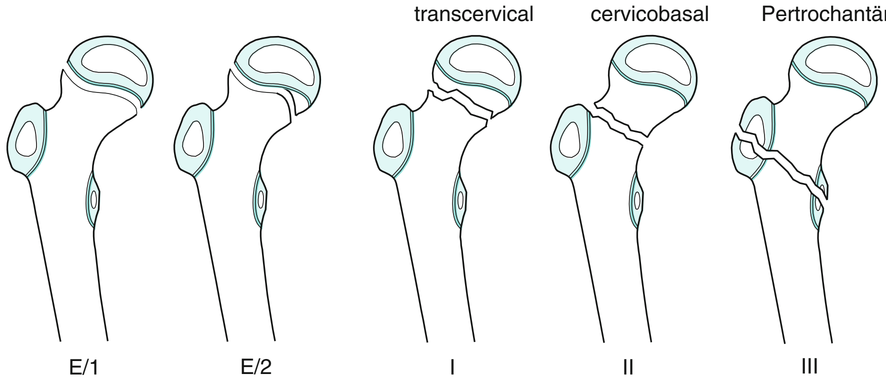


Fig. 29.13 Fractures of the proximal femur: AO pediatric comprehensive classification (Taken from: Kindertraumatologie Marzi; Publisher: Steinkopff)

29.8.5.2 Galeazzi Lesion

A radius shaft fracture with simultaneous ulna head luxation in the distal radial ulnar joint (DRUG) is called a classical Galeazzi fracture. This injury appears rarely in the infancy. In a complete luxation of the DRUG, an injury of the triangular fibrocartilaginous complex must always be excluded. Unstable fractures and (besides the unstable fractures) dislocations of the radius >10° require an operational therapy with reduction and stabilization of the radius fracture.

29.8.6 Lower Extremity

29.8.6.1 Proximal Femur

Injuries of the proximal femur are extremely rare in infancy and are usually associated with a severe trauma as well as accompanying injuries. Due to the vessel supply of the head of the femur and the femoral neck, danger of femur head necrosis or a growth disturbance with following femoral neck shortening exists in all injuries.

For this reason, all dislocated fractures have to be considered as emergency indications, which have to be reduced as quickly as possible. If necessary, a relief of the intracapsular hematoma and stabilization should be performed so as not to endanger the blood circulation of the proximal femur. The therapy is therefore performed conservatively, only in exceptional cases, with a pelvic leg cast in babies and infants. Otherwise, a closed or open reduction and stabilization is performed, preferably with cannulated screws, and alternatively by a plate or ESIN in type III fractures. Epiphyseal fractures are rare. The traumatic epiphysiolysis is also extremely rare and appears mostly as a birth trauma. This rare injury has to be separated clearly from the nontraumatic epiphysiolysis in the adolescence. The classification follows the AO pediatric comprehensive classification (Fig. 29.13).

Traumatic hip luxation also appears in context of high-energy traumas in adolescents. They may also appear in infants caused by bagatelle traumas. It should be reduced as fast as possible under general anesthesia; later reductions (>6 h after trauma) have a worse prognosis. A following CT scan excludes accompanying osseous injuries of the pelvis or the femoral head. If there is any suspicion of a femoral head necrosis, an MRI control should be performed.

29.8.6.2 Diaphyseal Femur

Femoral shaft fractures are usually a result of high-energy traumas. Therefore, accompanying injuries always have to be expected. In X-ray diagnostics, one plane is sufficient in all dislocated fractures, whereas the adjoining joints have to be displayed in order to exclude further fractures or an accompanying hip luxation. The further distal the fracture is located, the greater the possibilities are of a spontaneous correction of the dislocation. Since a relevant leg elongation has to be expected due to extended growth stimulation because of the necessary remodeling, an anatomical reduction should be performed to avoid a relevant post-traumatic leg-length difference.

The choice of the therapy method mainly corresponds with the age of the child. While conservative treatment by overhead extension and/or pelvis-leg cast is the method of choice in children up to the 3rd year of life, operative therapy is preferred in older children. This offers greater comfort to the child and the family and enables a faster mobilization and little hospitalization. The method of the choice for the simple diaphyseal

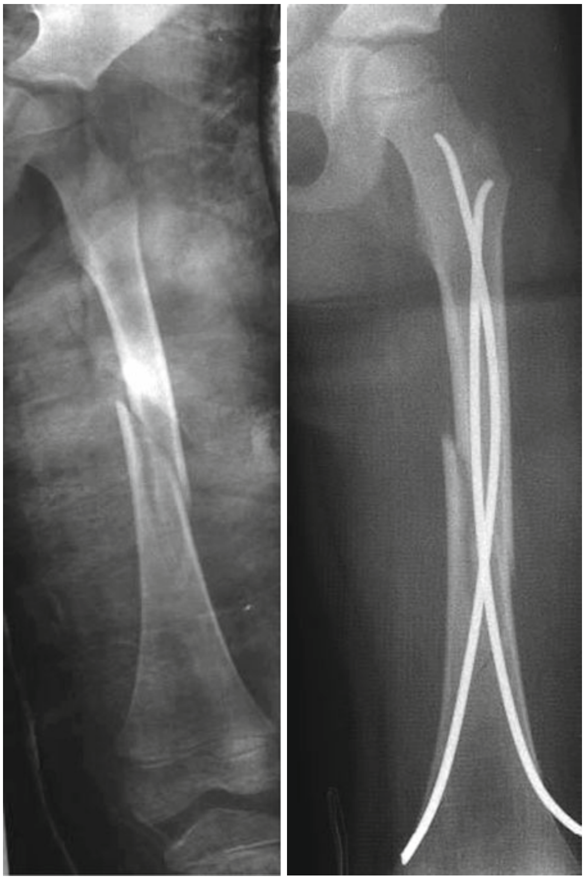


Fig. 29.14 Diaphyseal femur shaft fracture in a 6-year-old and stabilization by ESIN

transverse fracture is stabilization by ESIN (Fig. 29.14). However, diagonal fractures can be also stabilized by utilization of the biomechanical principle of the three-point support. By introduction of the so-called end caps (Synthes®), lengthwise-unstable diagonal fractures can also be stabilized without a secondary compression. External fixation offers an alternative method of supply in all unstable fractures. Plate osteosynthesis is usually only used in exceptional cases. Supply by an intramedullary nail has to be considered in large and heavy adolescents, if the ESIN has reached its limits. In this case, the danger of vessel lesions at the entrance of the nail with following head necrosis exists.

29.8.6.3 Distal Femur

Metaphyseal bulge fractures can be separated from complete fractures in this area. The therapy of the stable compression/bulge fractures can usually be effected conservatively by fixation in an upper leg cast, and in small children by a pelvis-leg cast. The often-existing little antecurvation position needs no correction. An X-ray control should be performed after 8 days in the complete fractures to exclude a secondary dislocation. Unstable or dislocated fractures are reduced close and are fixed with percutaneous crossed K-wire osteosynthesis. In these cases, an additional immobilization in an upper leg cast is necessary.

The closer the fracture is located to the physis, the more often growth disturbances have to be expected. There is often a partial dorsal closure of the physis with a consecutive antecurvation position. A stimulation of growth with influence of the leg length has to be expected according to the age and the amount of the necessary remodeling.

29.8.7 Fractures of the Knee

Fractures in the area of the knee mainly arise in the context of sports injuries. The diagnosis can be difficult because of irregular centers of ossification. In unclear cases, an MRI is helpful to exclude inner knee injuries. The reduction should always be performed under general anesthesia with definitive stabilization to avoid further complications by secondary dislocations. The following fractures can be differentiated in the knee:

Extra-articular fractures
- Epiphysiolysis of the distal femur and the proximal tibia
- Metaphyseal osseous side ligament avulsions
- Extra-articular avulsions of the tuberosity

Intra-articular fractures
- Epiphyseal fracture of the distal femur and the proximal tibia
- Patella fracture
- Eminentia intercondylar avulsion
- Intra-articular avulsion of the tuberosity

29.8.7.1 Epiphysiolysis of the Distal Femur

Epiphysiolysis belong to the most common injuries of the distal femur. Mostly, a physeal solution is found with a small metaphyseal wedge. In many cases, this fracture can be found as a birth trauma injury or as a battering injury in infants. A lesion of the vessel-nerve bundle can occur because of a dorsal dislocation, and angiography should be performed in uncertain cases to exclude a vessel lesion. Undislocated fractures can be

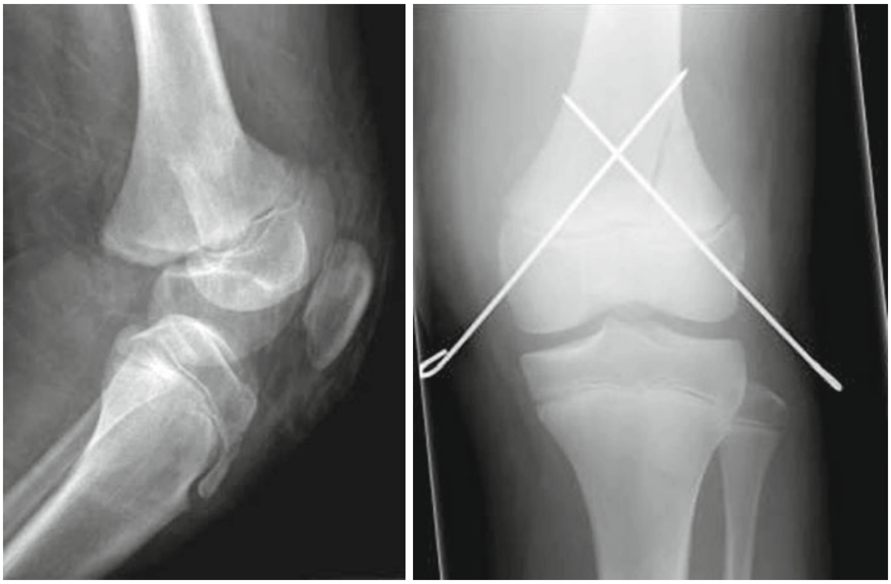


Fig. 29.15 Salter II fracture of distal femur in a 13-year-old and after K-wire stabilization

treated conservatively in an upper leg cast for 5 weeks. All fractures with an axis kink as well as a side-to-side dislocation of more than one-fifth of the metaphyseal width should be reduced under general anesthesia because the spontaneous correction capability of axis kinks is limited. If this is not successful, for example, because of a tissue interposition, open treatment has to be performed.

To secure the reduction result, crossed, percutaneous K-wire osteosynthesis is inserted (Fig. 29.15). If the size of the metaphyseal wedge is large enough it can be fixed by a screw osteosynthesis. Partial blocking growth disturbances occur often, so that the children have to be controlled regularly until completion of growth, up to 2 years after trauma.

29.8.7.2 Epiphyseal Fractures of the Distal Femur

In epiphyseal fractures, injuries with open physis, the epiphyseal fractures (Salter III), and the epimetaphyseal fractures (Salter IV) can be differentiated from the so-called transition fractures in adolescents with already-beginning physis closure. Usually a severe trauma can be found as a cause of accident. A vessel lesion has to be excluded due to the proximity of the vessel-nerve bundle. If there is a suspicion of an inner knee injury or an insecure radiological result, an MRI can be helpful. The reconstruction of the articular surface is the therapeutic aim. Therefore, no spontaneous corrections can be included in the therapy regime but an anatomical reduction has to be attempted. All fractures with an articular step or a fracture dehiscence of >2 mm require an operational intervention. Undislocated fractures can be treated in an upper leg cast for 4–5 weeks, whereas a radiological control should be performed to exclude a secondary dislocation after 1 week. Dislocated fractures are reduced open and are stabilized by screw osteosynthesis under compression of the fracture gap. Clinical controls are necessary to detect possible posttraumatic growth disturbances.

29.8.7.3 Epiphyseal Fractures of the Proximal Tibia

Solutions of the physis with (Salter II) or without metaphyseal (Salter I) participation are extremely rare. Due to the proximity of the vessel-nerve bundle, dislocations can lead to vessel lesions with severe circulation disturbances analogous to knee joint luxations in adults. If there is any suspicion, an angiography to exclude vessel lesions should be performed. Axis dislocations, especially in the frontal plane, are only corrected insufficiently and can lead to an extreme genu valgum and varum position. Therefore, a reduction with correct axis position should be aimed for. Blocking growth disturbances can lead to axis dislocations because of early physis closure. Undislocated fractures can be treated conservatively in an upper leg cast. Dislocated fractures can mostly be reduced closed and retained in an upper leg cast if stable; in cases of instability, a percutaneous K wire osteosynthesis is performed.

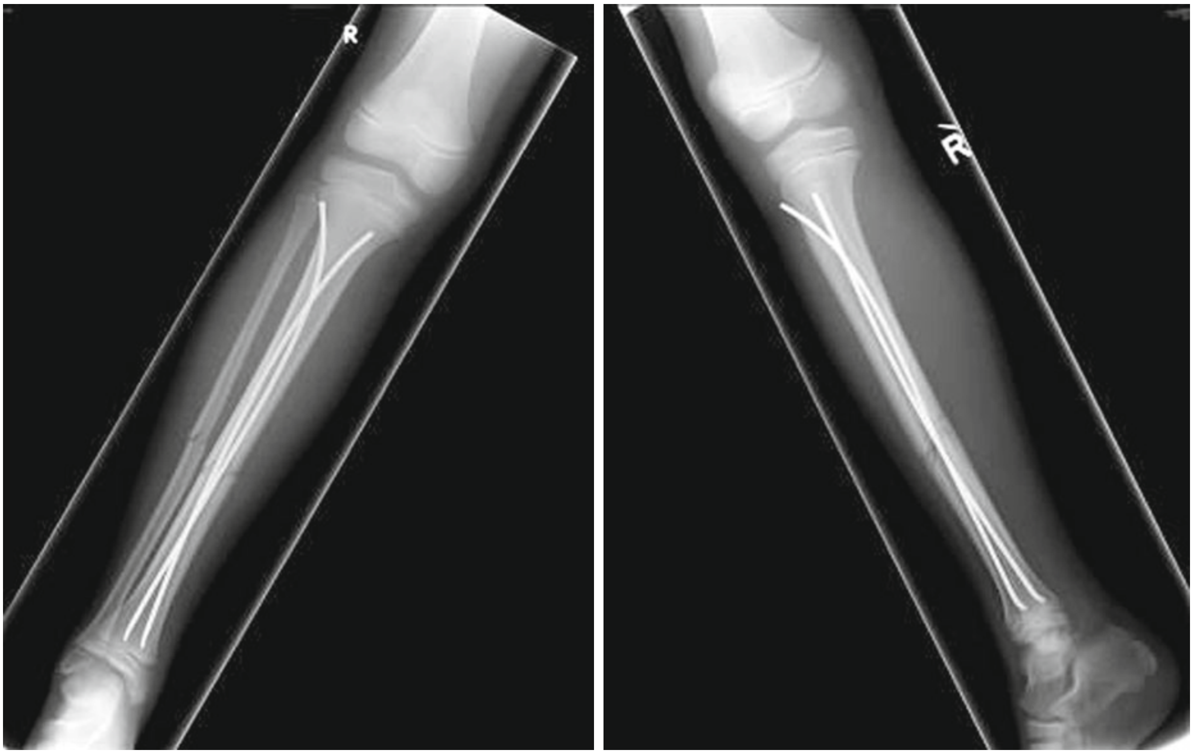


Fig. 29.16 Unstable diaphyseal fracture of the lower leg after ESIN osteosynthesis

29.8.7.4 Fractures of the Patella

Fractures of the patella are rarer in children than in adults because the patella is mostly cartilage and the ligaments are lax. Osteochondral fractures as concomitant injuries of a patella luxation are found more often. Transverse fractures can be differentiated from longitudinal fractures, from osteochondral avulsion fractures, and from central osteochondral defects.

The aim of therapy is the reconstruction of the extension muscles and ligaments, as well as the reconstruction of the articular surface. Undislocated fractures (mainly longitudinal fractures) can be treated conservatively in an upper leg tutor. Dislocated fractures are reduced open or arthroscopically assisted and are supplied by tension band or screw osteosynthesis. Proximal or distal avulsion fractures can be fixed by a transosseous suture and osteochondral fragments can be stabilized by resorbable pins. The danger mainly exists in a continuance of a joint step, which can lead to a femoropatellar arthrosis. Pseudarthrosis only results in insufficient osteosynthesis.

29.8.7.5 Proximal Tibia

Unproblematic compression fractures must be differentiated from curvature fractures in the lower leg fractures. Because the compression fracture usually heals without complication, the curvature fracture tends to an increasing valgus dislocation because of partial growth stimulation. Therefore, no dislocations can be accepted, but a reduction with compression of the medial fracture gap has to be aimed for to decrease the risk of a valgising growth disturbance. Slightly dislocated (<10°) or undislocated fractures can be treated conservatively in an upper leg cast. A cast wedging can be performed on the 8th day to achieve a medial compression. Dislocated fractures are reduced closed and are fixed by compression osteosynthesis (e.g., plate osteosynthesis or external fixation).

29.8.7.6 Diaphyseal Lower Leg

Lower leg fractures number among the most common fractures of the lower extremity. In two-thirds of the cases, only the tibia is affected; in one-third of the cases a complete fracture exists. Depending on the necessary remodeling, a leg length elongation of approximately 0.5–1 cm can occur due to growth stimulation. For this reason, no greater dislocations should be left to spontaneous correction. A varus of 5°, ante- and recurvation of 10°, and no valgus or rotation dislocation are the limits under the 10 years of age.

Isolated tibia fractures are to be considered as stable and can be treated conservatively in an upper leg cast. They tend to a varus dislocation because of muscle tension and the blocking effect of the intact fibula, so that a position control should be performed after 8 days. A cast wedging can antagonize the varus dislocation. Complete lower leg fractures are mostly instable, thus, an operative stabilization by ESIN or external fixation is recommended (Fig. 29.16). Stable, undisplaced fractures can also be treated conservatively in an upper leg cast. A position control should also be performed after 8 days because the fracture tends to a valgus dislocation caused by muscle tension and the missing influence of the fibula.

The stress fracture should be mentioned as a special fracture type. The tibia is the most common localization of stress reactions such as stress fractures, which occur with an increase in sports activities in children. The so-called “toddler’s fracture” is a special type of the stress fracture. It appears in the infant because of an uncommon stress at the beginning of walking without associated trauma and can be recognized by a corresponding callus formation in the X-ray.

29.8.7.7 Distal Tibia/Fibula

At the metaphysis, one must differentiate between unproblematic bulge fractures and curvature fractures. The latter tend to an increasing axis dislocation because of partial stimulation of the adjoining physis. Because of the potential of spontaneous correction, axis dislocations up to 10° can be accepted in children under the 10th year of life. If a stable osteosynthetical supply by ESIN is not possible, the alternative of external fixation is given especially in the dia-metaphyseal transition.

We differentiate the physis participating fractures of the distal tibia between physis dislocations with or without metaphyseal wedge and epiphyseal fractures (Salter III and also to speak of transitional fractures). Because of the potential of spontaneous correction, axis dislocations up to 20° can be accepted in children under the 10th year of life. Dislocated fractures can usually be reduced closed. An elastic resistance can often be found that allows the epiphysis to slip off. In these cases, a fixation by percutaneous inserted K-wires is necessary after reduction. An open reduction is only necessary in exceptional cases. In cases of joint fractures, an anatomical reduction should always be aimed for, whereas a limit of tolerance of a 2 mm fracture gap can be accepted (Fig. 29.17). A spontaneous correction cannot be expected. The supply is performed by compression osteosynthesis by inserted screws parallel to the joint surface and the physis.

An occurrence of growth disturbances is likely after all fractures, whereas a partial growth inhibition with increasing axis dislocation comes to the fore. Transitional fractures are an exception in which a relevant growth disturbance is not to be expected due to an already started physis closure because of the children’s age.

Fractures of the distal fibula usually occur in combination with an epiphyseal solution of the distal tibia. Therapeutically, a reduction and stabilization of the tibial fracture is sufficient, so that an osteosynthetic supply of the fibula is rarely necessary. Plastic deformations correct themselves during the following growth if the syndesmosis remains intact. Isolated fractures of the distal fibula are rare and usually are only a little dislocated. They can usually be treated conservatively in a lower leg cast.

29.9 AO Pediatric Comprehensive Classification of Long Bone Fractures

This classification system has been developed and validated by the AO pediatric classification group in collaboration with the AO pediatric expert group under project management and methodological guidance of AO clinical investigation and documentation.

The fracture classification consists of up to six codes (Fig. 29.18):

1. *Bone:* In accordance with the Mueller classification of long bone fractures in adults, the first digit represents the affected part of the upper or lower extremity (Fig. 29.19):
   1 = humerus
   2 = forearm
   3 = femur
   4 = lower leg
2. *Segment:* The metaphysis is identified by a square whose side has the same length as the widest part of the physis. For paired bones, both bones must be included in the square.Metaphyseal fractures are identified through the position of the square; the

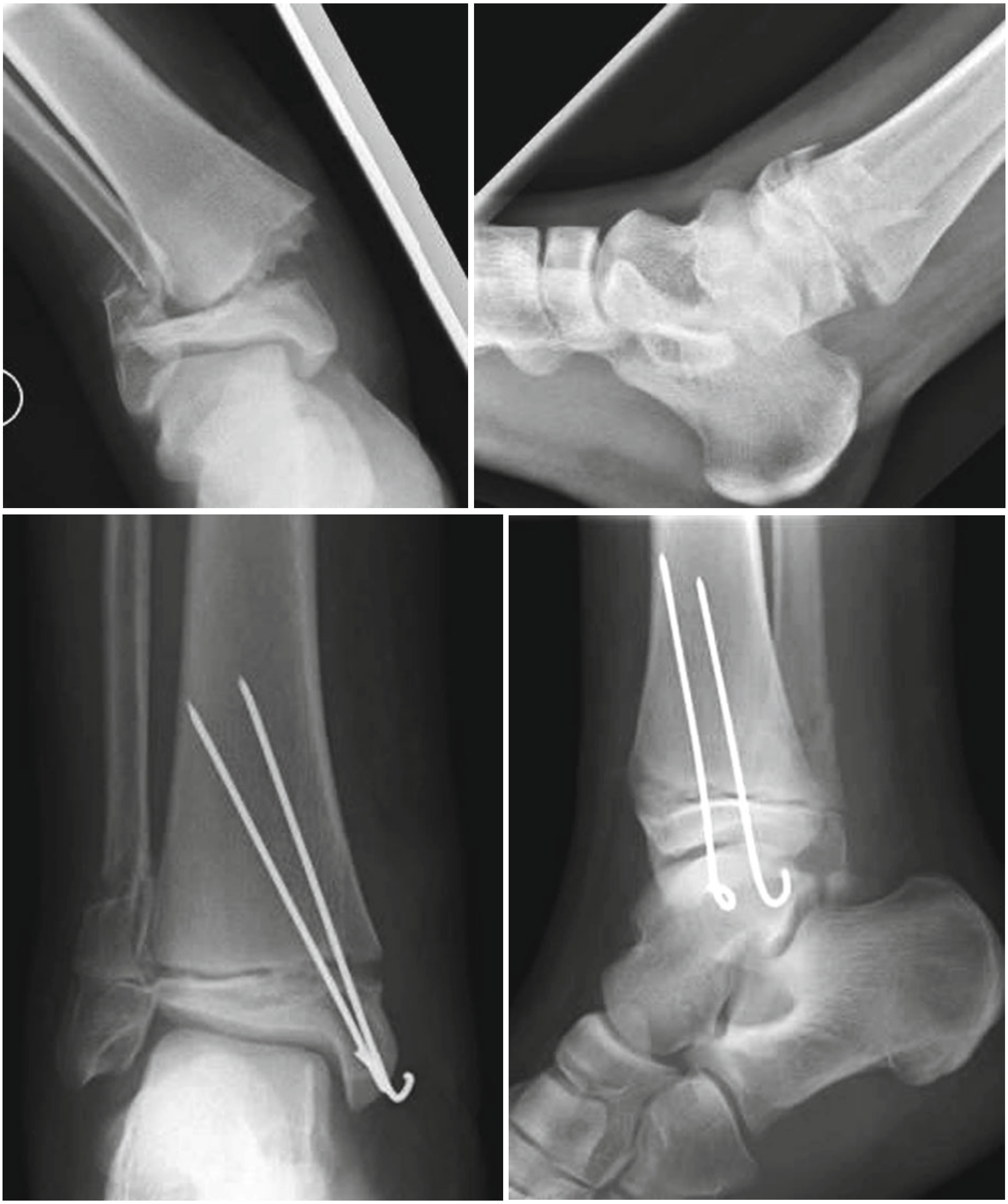


Fig. 29.17 Salter II fracture in a 13-year-old boy before and after reduction and K-wire stabilization

center of the fracture line must be located in the square; (Fig. 29.20). At the proximal femur, the metaphysis is located between the physis of the head and the intertrochanteric line.

1 = proximal: including subsegments epiphysis (E) and metaphysis (M)
2 = shaft/diaphysis (D)

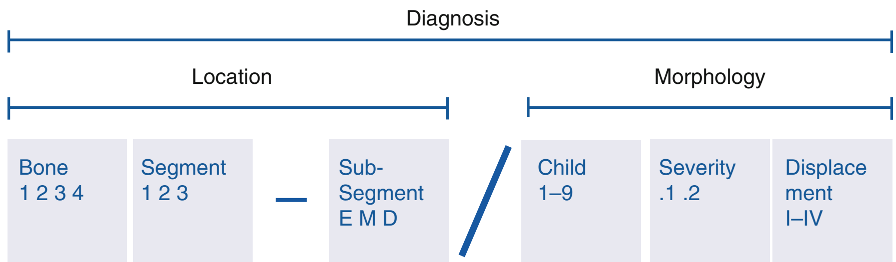


Fig. 29.18 Overall structure of the pediatric fracture classification (Taken from: AO Foundation/Education)

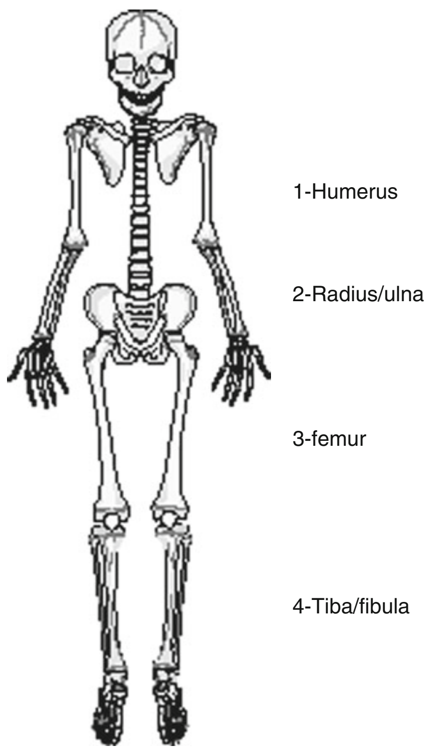


Fig. 29.19 Location (Taken from: AO Foundation/Education)

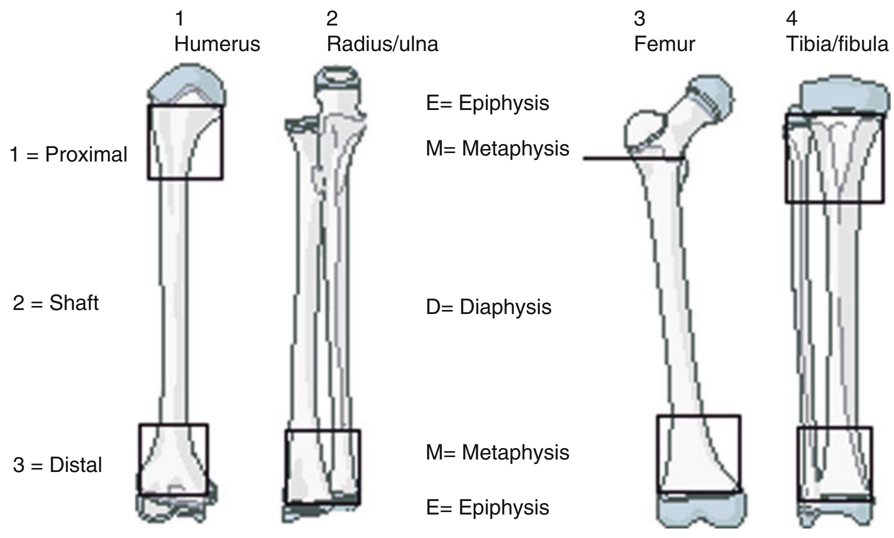
3 = distal: including subsegments metaphysis (M) and epiphysis (E)

3. *Subsegment* (Fig. 29.20):
   E = epiphysis
   M = metaphysis
   D = diaphysis
4. *Child code:* All relevant pediatric fractures were transformed into a child code, which is specific to one of the fracture subsegment localization (Fig. 29.21).
   Epiphysis
   - E/1 = Salter–Harris I
   - E/2 = Salter–Harris II
   - E/3 = Salter–Harris III
   - E/4 = Salter–Harris IV
   - E/5 = Tillaux (two-plane) fracture
   - E/6 = triplane fracture
   - E/7 = ligament avulsion
   - E/8 = Flake fracture
   - E/9 = other fractures

   Metaphysis
   - M/2 = incomplete fractures (torus, buckle, greenstick)
   - M/3 = complete fracture
   - M/7 = ligament avulsion
   - M/9 = other fractures

   Diaphysis
   - D/1 = bowing fractures
   - D/2 = greenstick fractures
   - D/4 = complete transverse fracture ≤30°
   - D/5 = complete oblique fracture >30°
   - D/6 = Monteggia fractures
   - D7 = Galeazzi fracture
   - D/9 = other fractures
5. Severity: A grade of fracture severity (Fig. 29.22).
   - 1 = simple; two main fragments
   - 2 = wedge or complex; two main fragments and at least one intermediate fragment
6. Displacement of special fractures: Additional codes are given according to the grade of displacement of supracondylar fractures, radial neck fractures, and femoral neck fractures:
   - Supracondylar fractures:
     – I = stable; incomplete fracture. Rogers' line still intersects the capitulum AND in the a.p. view there is no more than 2 mm valgus or varus fracture gap.
     – II = stable; incomplete fracture. Rogers' line does not intersect the capitulum OR in the a.p. view, there is no more than 2 mm valgus or varus fracture gap.

Fig. 29.20 Segment and subsegment (Taken from: AO Foundation/Education)



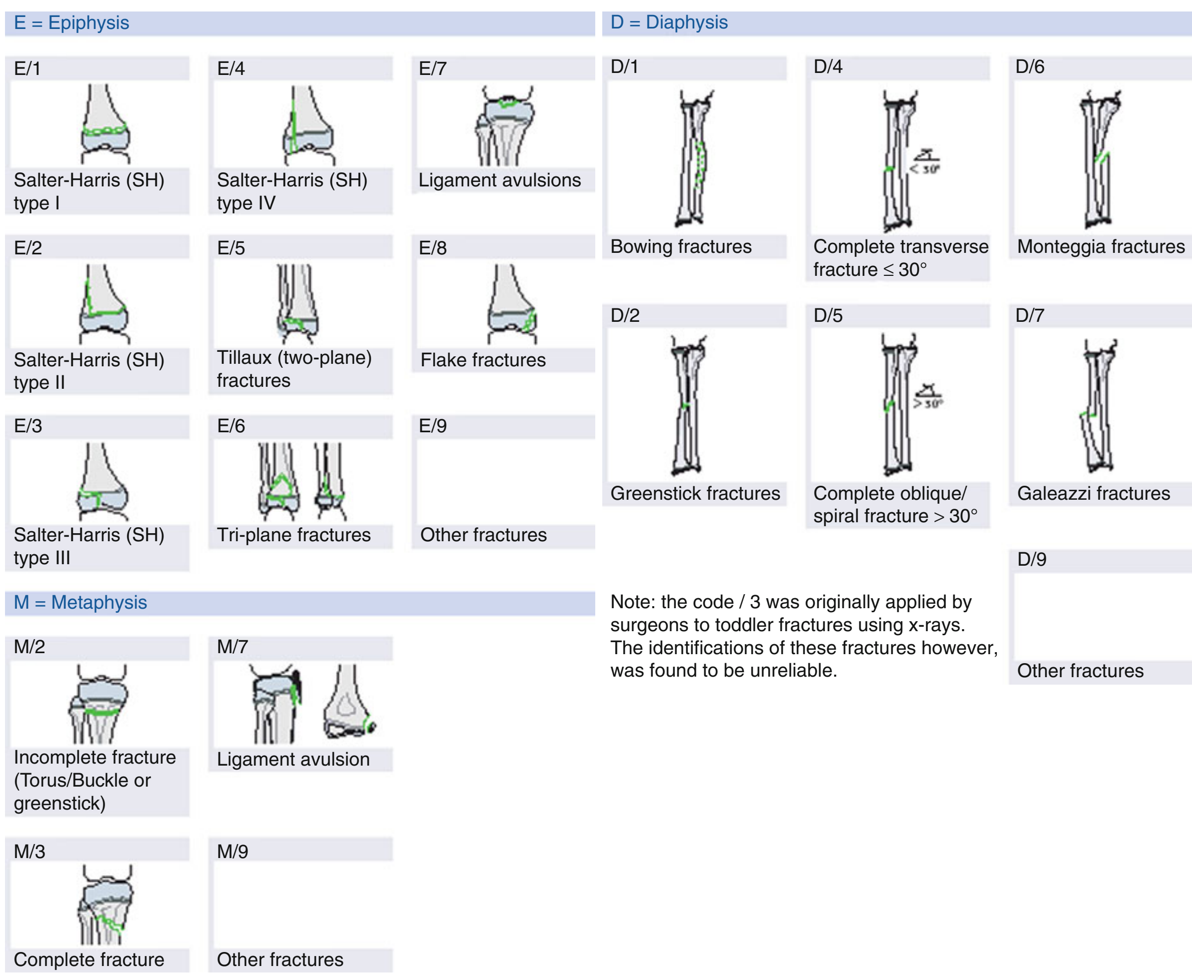


Fig. 29.21 Child code (Taken from: AO Foundation/Education)

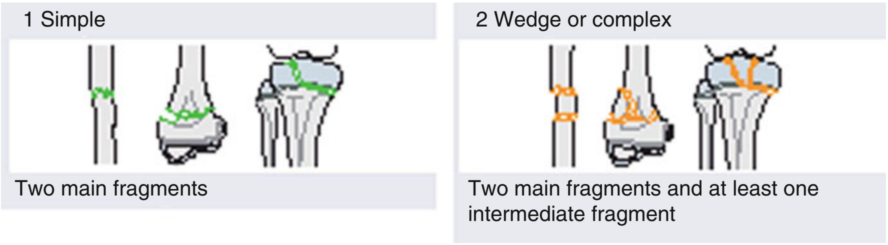


Fig. 29.22 Severity (Taken from: AO Foundation/Education)

- III = unstable; complete fracture. No bone continuity, but still some contact between the fracture planes.
- IV = unstable; complete fracture. No bone continuity and no contact between the fracture planes.

- Radial neck fractures:
  - I = no angulation and no displacement
  - II = angulation with displacement up to half of the bone's diameter
  - III = angulation with displacement more than half of the bone's diameter.
- Femoral neck fractures: Epiphyseolysis, with or without metaphyseal wedge, is coded as Type E epiphyseal fractures (E/1 or E/2). Fractures of the femoral neck are coded as Type M metapyhseal fractures coded I–III. The intertrochanteric line limits the metaphysic.
  - I = mid-cervical
  - II = basicervical
  - III = transtrochanteric

Further Rules

- Fracture in paired bones: Except for Monteggia and Galeazzi lesions, if paired bones are fractured with the same child pattern, a single classification code should be used with the severity code defining the worst of the two bones. If a single bone is fractured, r for radius, u for ulna, t for tibia, or f for fibula should be added after the segment code (e.g., isolated fracture of the ulna = "22u"). If paired bones are fractured with different child patterns, each bone must be coded separately, including the corresponding letter (r, u, t, f).
- Fractures of the apophysis are considered as metaphyseal injuries.
- Transitional fractures with or without metaphyseal wedge are classified as epiphyseal injuries.
- Ligament injuries are classified as epiphyseal or metaphyseal, depending on whether they are intra-articular or extra-articular. The side of the ligament injury is indicated by the small letter u for ulnar/medial or r for radial/lateral for the humerus and t for tibial/medial and f for fibular/lateral for the femur.

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