22 Distal Femur Fractures

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].

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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

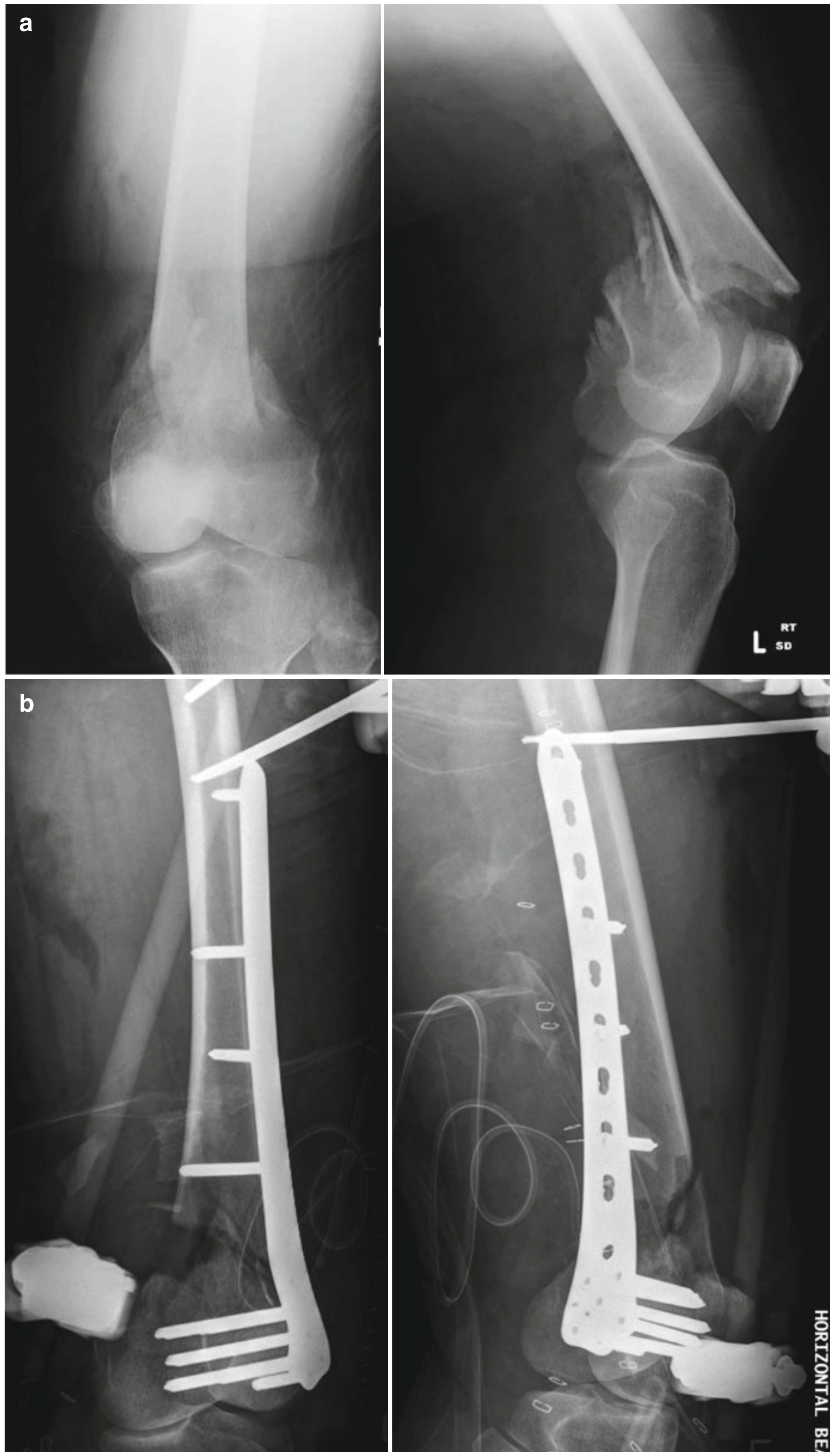
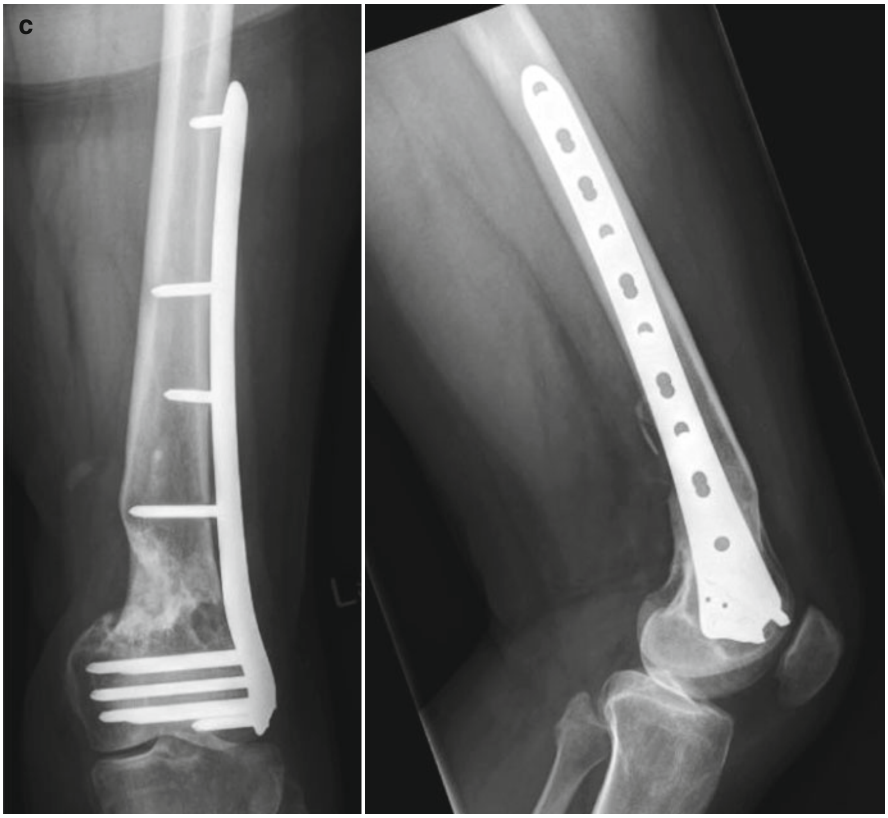


Fig. 22.1 (**a**) A 47-year-old female was caught between two cars, with crushing injury of the left thigh (IIIb open 33.A3 with bone loss). On day 1, the patient underwent a washout and debridement of the wound with application of a knee-spanning external fixator. (**b**) On day 3, the patient had further 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**)

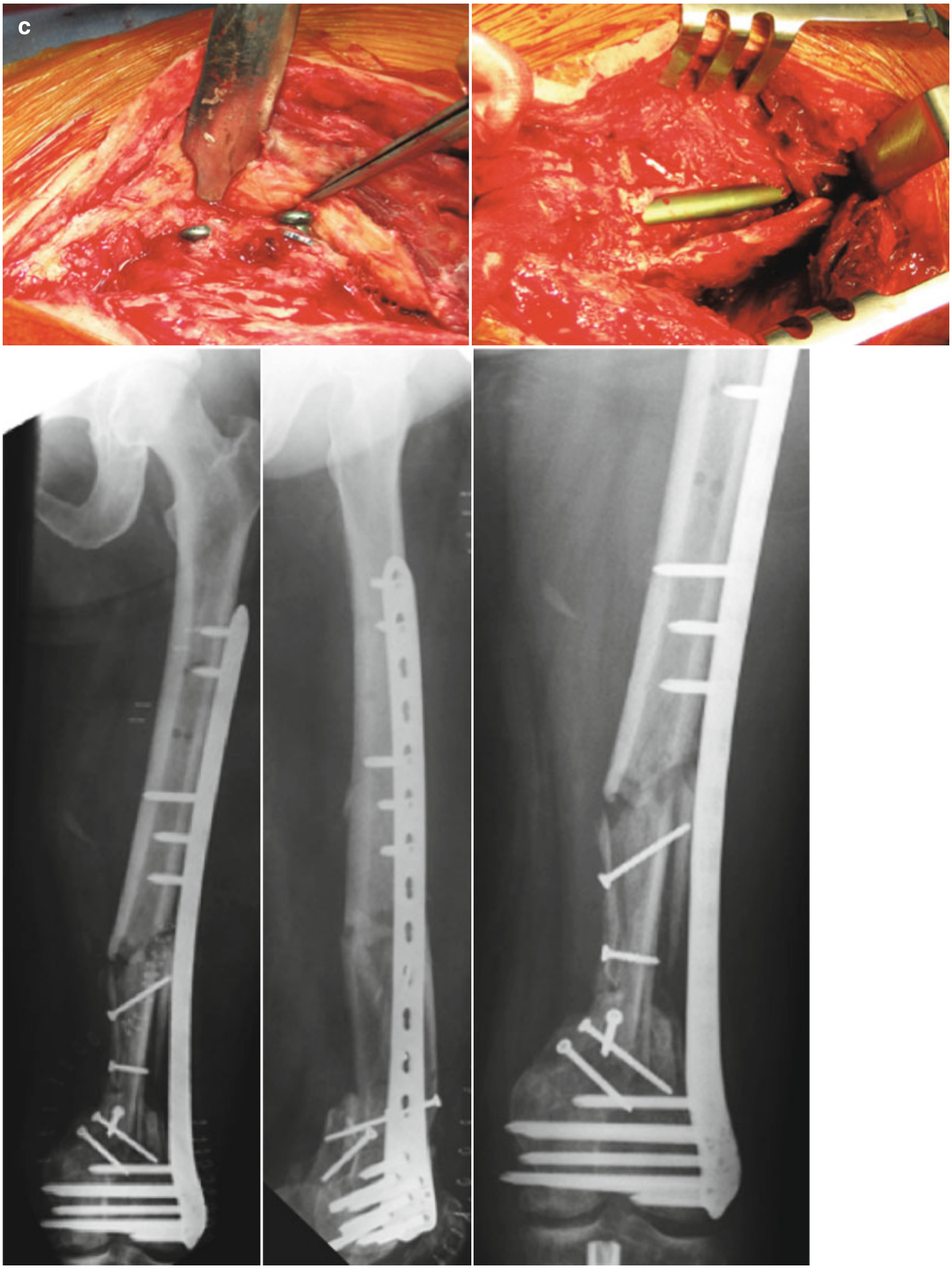


Fig. 22.3 (continued)

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

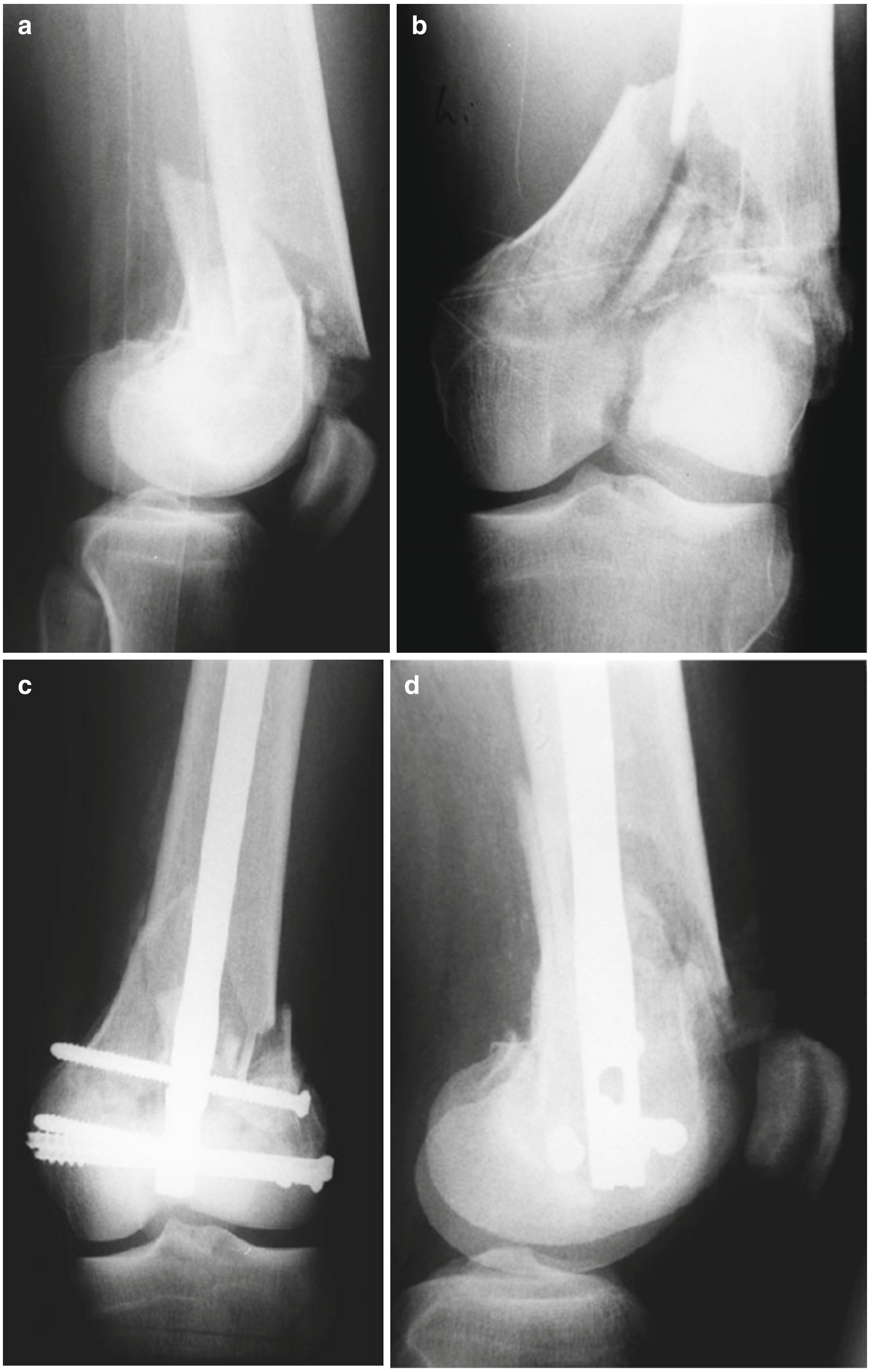


Fig. 22.4 Distal femur fracture after an accident (AO-Classification C 2). X-rays of the day of accicdent (**a**, **b**). Reconstruction of articular bone block with a lag screw and distal femoral nail. The x-ray 6 weeks postoperatively show a good reduction with beginning bone healing (**c**, **d**)

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].

References

1. Regazzoni P, Leutenegger A, Ruedi T, Staehelin F (1986) Initial experiences with the dynamic condylar screw in distal femoral fractures. Helv Chir Acta 53:61–64
2. Farouk O et al (1999) Minimally invasive plate osteosynthesis: does percutaneous plating disrupt femoral blood supply less than the traditional technique? J Orthop Trauma 13: 401–406
3. Bolhofner BR, Carmen B, Clifford P (1996) The results of open reduction and internal fixation of distal femur fractures using a biologic (indirect) reduction technique. J Orthop Trauma 10:372–377
4. Lucas SE, Seligson D, Henry SL (1993) Intramedullary supracondylar nailing of femoral fractures. A preliminary report of the GSH supracondylar nail. Clin Orthop Relat Res 296:200–206
5. Krettek C, Schandelmaier P, Miclau T, Tscherne H (1997) Minimally invasive percutaneous plate osteosynthesis (MIPPO) using the DCS in proximal and distal femoral fractures. Injury 28(Suppl 1):A20–A30
6. Farouk O et al (1997) Minimally invasive plate osteosynthesis and vascularity: preliminary results of a cadaver injection study. Injury 28(Suppl 1):A7–A12
7. Krettek C et al (1997) Transarticular joint reconstruction and indirect plate osteosynthesis for complex distal supracondylar femoral fractures. Injury 28(Suppl 1):A31–A41
8. Baumgaertel F, Gotzen L (1994) The “biological” plate osteosynthesis in multi-fragment fractures of the para-articular femur. A prospective study. Unfallchirurg 97: 78–84
9. Baumgaertel F, Perren SM, Rahn B (1994) Animal experiment studies of “biological” plate osteosynthesis of multi-fragment fractures of the femur. Unfallchirurg 97:19–27
10. Kregor PJ, Stannard JA, Zlowodzki M, Cole PA (2004) Treatment of distal femur fractures using the less invasive stabilization system: surgical experience and early clinical results in 103 fractures. J Orthop Trauma 18:509–520, doi:00005131-200409000-00006 [pii]
11. Schutz M et al (2001) Minimally invasive fracture stabilization of distal femoral fractures with the LISS: a prospective multicenter study. Results of a clinical study with special emphasis on difficult cases. Injury 32(Suppl 3):SC48–SC54
12. Funovics PT, Vecsei V, Wozasek GE (2003) Mid- to long-term clinical findings in nailing of distal femoral fractures. J Surg Orthop Adv 12:218–224
13. Jawadi AH, Letts M (2003) Injuries associated with fracture of the femur secondary to motor vehicle accidents in children. Am J Orthop (Belle Mead NJ) 32:459–462; discussion 462
14. Bengner U, Ekbom T, Johnell O, Nilsson BE (1990) Incidence of femoral and tibial shaft fractures. Epidemiology 1950–1983 in Malmo, Sweden. Acta Orthop Scand 61: 251–254
15. Siliski JM, Mahring M, Hofer HP (1989) Supracondylar-intercondylar fractures of the femur. Treatment by internal fixation. J Bone Joint Surg Am 71:95–104
16. Sanders R, Regazzoni P, Ruedi TP (1989) Treatment of supracondylar-intracondylar fractures of the femur using the dynamic condylar screw. J Orthop Trauma 3:214–222
17. Khalafi A, Curtiss S, Hazelwood S, Wolinsky P (2006) The effect of plate rotation on the stiffness of femoral LISS: a mechanical study. J Orthop Trauma 20:542–546. doi:10.1097/01.bot.0000244996.45127, ad00005131-200609000-00004 [pii]
18. Zlowodzki M, Williamson S, Cole PA, Zardiackas LD, Kregor PJ (2004) Biomechanical evaluation of the less invasive stabilization system, angled blade plate, and retrograde intramedullary nail for the internal fixation of distal femur fractures. J Orthop Trauma 18:494–502, doi:00005131-200409000-00004 [pii]
19. Henderson CE, Kuhl LL, Fitzpatrick DC, Marsh JL (2011) Locking plates for distal femur fractures: is there a problem with fracture healing? J Orthop Trauma 25(Suppl 1):S8–S14. doi:10.1097/BOT.0b013e3182070127, 00005131-201102001-00003 [pii]
20. Ricci WM, Loftus T, Cox C, Borrelli J (2006) Locked plates combined with minimally invasive insertion technique for the treatment of periprosthetic supracondylar femur fractures above a total knee arthroplasty. J Orthop Trauma 20:190–196, doi:00005131-200603000-00005 [pii]

21. Hierholzer C, von Ruden C, Potzel T, Woltmann A, Buhren V (2011) Outcome analysis of retrograde nailing and less invasive stabilization system in distal femoral fractures: a retrospective analysis. Indian J Orthop 45:243–250. doi:10.4103/0019-5413.80043, IJOrtho-45-243 [pii]
22. Kolb W (2008) Fixation of distal femoral fractures with the less invasive stabilization system: a minimally invasive treatment with locked fixed-angle screws. J Trauma 65:1425–1434. doi:10.1097/TA.0b013e318166d24a, 00005373-200812000-00036 [pii]
23. Grass R, Biewener A, Rammelt S, Zwipp H (2002) Retrograde locking nail osteosynthesis of distal femoral fractures with the distal femoral nail (DFN). Unfallchirurg 105:298–314
24. Davison BL (2003) Varus collapse of comminuted distal femur fractures after open reduction and internal fixation with a lateral condylar buttress plate. Am J Orthop (Belle Mead NJ) 32(27–30)
25. Althausen PL, Lee MA, Finkemeier CG, Meehan JP, Rodrigo JJ (2003) Operative stabilization of supracondylar femur fractures above total knee arthroplasty: a comparison of four treatment methods. J Arthroplasty 18:834–839, doi:S0883540303003395 [pii]
26. Kolmert L, Wulff K (1982) Epidemiology and treatment of distal femoral fractures in adults. Acta Orthop Scand 53: 957–962
27. Dominguez I, Moro Rodriguez E, De Pedro Moro JA, Cebrian Parra JL, Lopez-Duran Stern L (1998) Antegrade nailing for fractures of the distal femur. Clin Orthop Relat Res 350:74–79
28. Leung KS, Shen WY, So WS, Mui LT, Grosse A (1991) Interlocking intramedullary nailing for supracondylar and intercondylar fractures of the distal part of the femur. J Bone Joint Surg Am 73:332–340
29. Seifert J et al (2003) Retrograde fixation of distal femoral fractures: results using a new nail system. J Orthop Trauma 17:488–495
30. Watanabe Y et al (2002) Second-generation intramedullary supracondylar nail for distal femoral fractures. Int Orthop 26:85–88
31. Ingman AM (2002) Retrograde intramedullary nailing of supracondylar femoral fractures: design and development of a new implant. Injury 33:707–712, doi:S0020138302000190 [pii]
32. Handolin L, Pajarinen J, Lindahl J, Hirvensalo E (2004) Retrograde intramedullary nailing in distal femoral fractures – results in a series of 46 consecutive operations. Injury 35:517–522. doi:10.1016/S0020-1383(03)00191-8, S0020138303001918 [pii]
33. Dunlop DG, Brenkel IJ (1999) The supracondylar intramedullary nail in elderly patients with distal femoral fractures. Injury 30:475–484, doi:S0020-1383(99)00136-9 [pii]
34. Danziger MB, Caucci D, Zecher SB, Segal D, Covall DJ (1995) Treatment of intercondylar and supracondylar distal femur fractures using the GSH supracondylar nail. Am J Orthop (Belle Mead NJ) 24(684–690)
35. Gynning JB, Hansen D (1999) Treatment of distal femoral fractures with intramedullary supracondylar nails in elderly patients. Injury 30:43–46, doi:S0020138398002095 [pii]
36. Markmiller M, Konrad G, Sudkamp N (2004) Femur-LISS and distal femoral nail for fixation of distal femoral fractures: are there differences in outcome and complications? Clin Orthop Relat Res 426:252–257, doi:00003086-200409000-00040 [pii]
37. O'Driscoll SW, Keeley FW, Salter RB (1986) The chondrogenic potential of free autogenous periosteal grafts for biological resurfacing of major full-thickness defects in joint surfaces under the influence of continuous passive motion. An experimental investigation in the rabbit. J Bone Joint Surg Am 68:1017–1035
38. Schandelmaier P, Partenheimer A, Koenemann B, Grun OA, Krettek C (2001) Distal femoral fractures and LISS stabilization. Injury 32(Suppl 3):SC55–SC63
39. Merchan EC, Maestu PR, Blanco RP (1992) Blade-plating of closed displaced supracondylar fractures of the distal femur with the AO system. J Trauma 32:174–178
40. Rademakers MV, Kerkhoffs GM, Sierevelt IN, Raaymakers EL, Marti RK (2004) Intra-articular fractures of the distal femur: a long-term follow-up study of surgically treated patients. J Orthop Trauma 18(4):213–219