Acta Chir Orthop Traumatol Cech. 84, 2017, No. 5
p. 330–340

Intramedullary Nailing of Metaphyseal Fractures of the Lower Extremity

Nitrodřeňové hřebování metafyzárních zlomenin dolní končetiny

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Introduction

Intramedullary nailing is a worldwide accepted technique for stabilization of fractures of long bones. Technique, instruments and implants primarily have been developed for the fixation of short (transverse and oblique) diaphyseal fractures. First generation nails were hollow and slotted, which gave them some elasticity. When the tip of the nail passed the fracture gap, picked up the opposite fracture fragment and was driven further down, the longitudinal axis of the bone was restored and the extremity realigned. Bone length was restored by closure of the fracture gap. The tight connection between the deformable hollow nail and the inner cortex at the isthmus realized a press-fit, which achieved a very stable bone-implant construct. The nail had the function of a weight-shearing implant. Interlocked nails represent the second-generation nails. They changed the spectrum of indications for nailing considerably. Not only short middle-third shaft fractures, but shaft fractures of all types (from transverse to comminuted) and all localizations can be stabilized with an interlocked nail. Due to interlocking, length and rotation are controlled. The nail bridges the area of instability, being a weight-bearing implant. Small diameter, solid nails formed the next generation of nail implants. They were conceived for the provisional treatment of fractures with an enhanced risk of postoperative infection such as open fractures or closed fractures with severe soft tissue damage. They were increasingly used for minimal invasive treatment of closed fractures without soft tissue damage as well, as reaming was not necessary and endosteal blood supply less damaged. Nevertheless, it became clear that they were connected with a higher incidence of implant failure and revision surgery. Another development was the creation of nails with multiple and angular stable interlocking options. Major advantage is that high stability is obtained in the fracture fragment, in which multiple interlocking is used. This property gives the possibility of nailing fractures close to a joint with a short fracture segment (24). Nevertheless, intramedullary nailing of metaphyseal fractures remains controversial. Major complications to be avoided are malalignment, delayed union, nonunion and implant failure due to suboptimal fracture reduction (23).

Intramedullary nailing of metaphyseal fractures

The medullary canal of femur and tibia has its lowest diameter in the middle third of the shaft. Proximal and distal of the isthmus, the medullary canal widens to reach its largest diameter near to the metaphysis. Nailing of fractures at the isthmus therefore differs from nailing of proximal or distal fractures. Whereas the nail is incarcerated in the isthmus, it is not in the more proximal and distal sections of the bone. In the middle third of the shaft, the nail is in close contact with the inner cortex. The proximal and distal bone segments are realigned due to nail insertion. In the proximal and distal third, some space between the nail and the inner cortex remains. The fracture segments are not automatically realigned during nail insertion. As there is more space for the implant, it can be located eccentrically, outside the longitudinal axis of the medullary canal. Axis deviation of the broken bone is the consequence. To prevent malalignment every fracture, which is localized closer to the joint, has to be reduced before the nailing procedure starts and this reduction needs to be secured during nail insertion. When a proximal or distal fracture is not reduced, the interlocked nail will fix the fracture and axis deviation (25).

Reduction of the fracture and protection of reduction during nail insertion asks for preoperative planning. This planning involves understanding of the fracture through analysis of the fracture type and fracture plane in two X-rays, which are taken perpendicular to each other. The different steps of fracture reduction and nail insertion have to be planned including instruments and implants needed for each step (3). Nailing of fractures near to a joint therefore ask for individual solutions involving a whole armamentarium of surgical techniques.

Metaphyseal fractures of the femur

Proximal femur fractures represent a specific biomechanical challenge because of the center-column-diaphysis (CCD) angle, which moves the axis of load medial to the longitudinal axis of the femur. In this review, we exclude pertrochanteric and intracapsular femur fractures, as they need specific consideration. We here focus on fracture types, which start at the level of the lesser trochanter, the last regularly being involved in the

Fig. 1a–e. a – AP view of the left femur and hip of an 18-year-old male after motorcycle accident. There is a subtrochanteric fracture with additional avulsion of a medial cortical fragment below the lesser trochanter. The shorter upper line corresponds with the central axis of the proximal fragment. The longer lower line corresponds with the central axis of the distal fragment. The proximal fragment is nearly 25° abducted and exorotated (lesser trochanter is completely visible). When intramedullary nailing is performed through an entry portal at the tip of the greater trochanter (when the entry portal is situated at the crossing of the longer lower line with the greater trochanter), the proximal fragment will remain in abduction and exorotation; b – AP view of the left femur and hip after intramedullary nailing with UFN and spiral blade. The patient has been placed on the fracture table. Reduction of the proximal fragment was performed with longitudinal traction on the left leg only. The shorter upper line corresponds with the lateral cortex of the proximal fragment. The longer lower line corresponds with the lateral cortex of the distal fragment. No perfect alignment was obtained. The proximal fragment remained in 10° abduction; c – Lateral view of the left femur and hip after intramedullary nailing. Nearly 8°of flexion of the proximal fragment is visible with no direct bone contact between the proximal and distal fragment; d – AP view of the left femur and hip one and a half year after trauma. The fracture healed thanks to abundant callus formation. Slight abduction of the proximal fragment remained; e – Lateral view of the left femur and hip after one and a half year. The fracture is healed but the flexion of the proximal fragment remained.

fracture, and run more distally towards the shaft. They occur in two different patient populations: the younger male and the older female. In the younger male, the fractures are due to a high-energy trauma and typically are comminuted and have considerable fracture displacement. In the older female, the fracture is the consequence of a low-energy trauma. The trauma mechanism has a rotatory component and the fracture has a simpler fracture form, mostly a spiral type. In both groups, the proximal fracture fragment, which contains the femoral head and neck, is displaced: it is externally rotated, abducted and flexed due to the pulling forces of the attached muscles (30). Before nailing, the fracture needs to be reduced by closed or open means, lateral or medial displacement of fracture fragments diminished in case of comminution; and lengthening corrected by closure of the fracture gap. The patient is placed on a fracture table, which enables longitudinal traction on the broken leg and fluoroscopy views in two planes: the antero-posterior plane and the slightly oblique lateral to medial plane, which is parallel to the plane of the femoral neck. Longitudinal traction can be realized through a leather booth containing the foot of the patient or through a Steinmann pin, which is drilled in the distal femoral condyles. An alternative to the fracture table is using a large distractor or external fixator with the patient on a radiolucent table. The proximal pin is placed from lateral to medial behind the medullary canal at the level of the lesser trochanter; the second pin is placed from lateral to medial at the distal femoral condyles (25). Main disadvantage of placing the patient on a radiolucent table is that fluoroscopy in two planes is not possible without rotation of the broken leg. By ligamentotaxis, it is possible to partially realign the fracture fragments. But realignment will never be complete and additional reduction necessary. It may be misleading trying to reduce the proximal fragment with the nail. As the medullary canal of the proximal fragment is large or non-existing, its complete reduction by manipulation with the nail will not be successful. When the proximal fragment remains in abduction, external rotation and flexion after nail insertion, the fracture gap will not be close. There is a higher risk of delayed healing and nonunion; or healing with a varus deformity (Fig. 1a–e).

Several other methods can be used for the reduction of the proximal fragment. A Schanz' screw or Steinmann pin can be drilled just below the greater trochanter from lateral to medial and behind the medullary canal. The pin is connected with a T-handle and through manipulation is the proximal fragment adducted, derotated and extended. The first or second assistant has to keep this reduction through the whole procedure, until the inserted nail has been interlocked. This method is especially valid in case of transverse fractures or in case of fracture comminution, where there is no direct contact between the proximal and distal main fragment after reduction. In case of oblique or spiral fractures, it is recommended to completely close the fracture gap. This can be achieved with a pointed reduction forceps, which is inserted percutaneously or through a small lateral incision. In long spiral fractures, it is easier to keep reduction with a pointed reduction forceps as in shorter, oblique fractures (Fig. 2a–c) (16). A cerclage wire can be used and tightened around the reduced fracture to secure reduction during further manipulation. It should be inserted in a minimally invasive way with as less damage to the periosteum as possible. Tightening of the cerclage wire presses the fracture fragment against each other and closes the fracture gap. The wire gives stability to the fracture area, and also adds to the overall stability after nail insertion. We therefore recommend leaving the cerclage wire as part of the bone-implant construct (Fig. 3a–f) (8). Alternatively, the cerclage wire can be removed after finishing nail insertion and interlocking (10). Another method for provisional

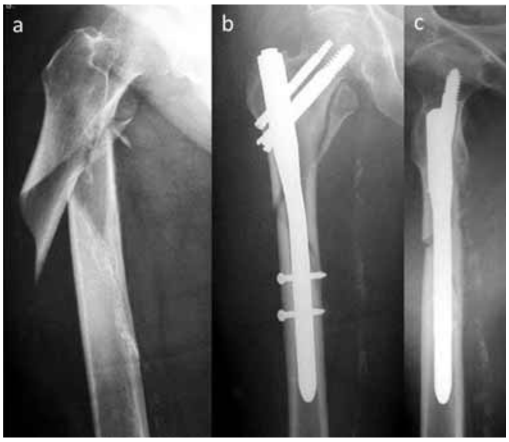


Fig. 2a–c. a – AP view of the right proximal femur and hip in a 75-year-old male. There is a spiral subtrochanteric fracture with avulsion of the lesser trochanter. An additional fissure towards distal, starting from the distal tip of the spiral fracture, is also visible in the distal fragment; b – AP view of the right proximal femur and hip after intramedullary nailing with PFN. The patient has been placed on the fracture table. The main fracture has been reduced with the help of two reduction clamps. Alignment has been restored; the fracture is nearly completely closed; c – Lateral view of the right proximal femur and hip after intramedullary nailing. Thanks to reduction with reduction forceps, the alignment is also perfectly restored in the lateral view. The remaining fracture gap can be closed through secondary dynamization by removal of the distal static screw (optional).

stabilization of the proximal femur fracture is using a short plate, which is inserted through a lateral incision and attached to the lateral cortex with monocortical screws. The stability of this construct is limited and special care has to be taken during manipulation avoiding avulsion of the plate and displacement of the fracture. The plate can be removed or left in place.

Once perfect alignment and/or fracture reduction have been achieved, the nailing procedure can start. Not all femoral nails are appropriate for fixation of proximal femoral fractures. The proximal head and neck fragment needs to be stabilized adequately to prevent important motion in the fracture area during postoperative mobilization and weight bearing. Non angular stable interlocking screws are not recommended. Angular stable screws, which use the long trajectory of the femoral neck into the femoral head, provide much higher stability (35). The ideal entry portal for the nail is depending of its design, especially of the medio-lateral curve of the nail in its proximal part. Straight nails need a medial entry portal in the piriformis fossa, which is in line with the central axis of the medullary canal. Curved nails need more lateral entry portals, be it on the tip of the greater trochanter or even lateral to the tip (22). On the lateral fluoroscopic view, the correct entry portal is situated in line with the curved central axis of the medullary canal. The entry portal can only be identified after fracture reduction. The medullary canal of the proximal fragment is opened with a drill guide, which is inserted through the ideal entry portal. Many "reconstruction" nails have a larger diameter in their proximal part. For this reason, the proximal fragment is opened with a drill of according diameter, which is placed over the drill guide. Drill and drill guide are removed and a longer drill guide inserted into the distal fragment. The tip of the drill guide should pass the isthmus and reach the center of the condylar block. Its correct position should be controlled in the antero-posterior and lateral fluoroscopic views. Long nails enhance stability and reduce the risk of femoral fractures at the tip of the short nails (34).

Once the entry portal and tip of the drill guide have been chosen correctly, we can be sure that the nail will ultimately find its correct and ideal position. Depending on the fracture morphology, the size of the medullary canal and the body weight of the patient, a smaller or larger diameter nail will be necessary. It is recommended

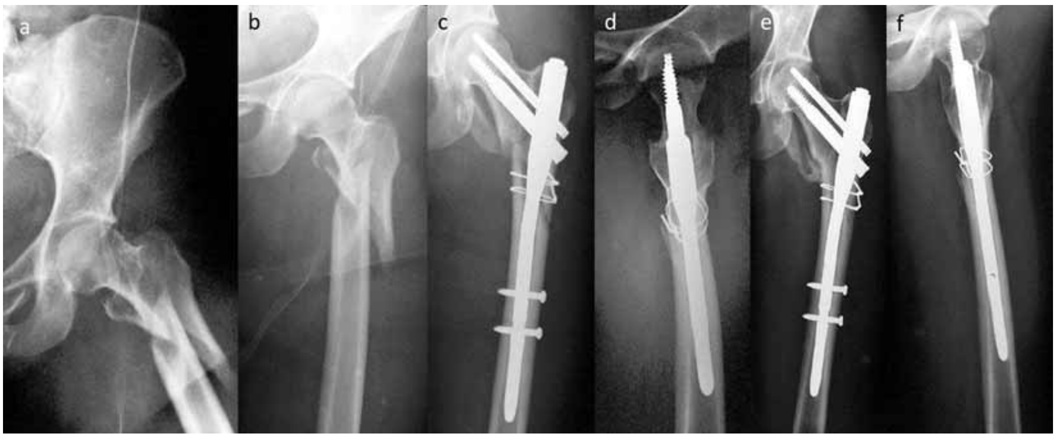


Fig. 3a–f. a – AP view of the left proximal femur and hip in a 34-year-old male after motorcar accident. There is a spiral subtrochanteric fracture with small avulsion of the tip of the lesser trochanter; b – Lateral view of the left proximal femur and hip after trauma; c – AP view of the left proximal femur and hip after intramedullary nailing with PFN. The patient has been placed on the fracture table. With longitudinal traction on the left leg, a satisfactory reduction of the fracture could not be obtained. Through a small lateral incision, the subtrochanteric fracture was reduced with two cerclage wires. A perfect alignment and adequate stability has been achieved before starting the nailing procedure; d – The lateral view of the left proximal femur and hip also shows a perfect alignment; e – AP view of the left proximal femur and hip after one and a half year, just before metal removal. An uneventful healing is visible. Due to high stability in the fracture plane, no callus formation is seen; f – Lateral view of the left proximal femur and hip showing complete healing.

to always ream the medullary canal to some amount. Nail insertion without previous reaming needs large forces and risks displacement of the reduced fracture. Gentle reaming opens the isthmus, enables the insertion of a larger diameter nail and promotes fracture healing due to the reaming debris (28) (see also proximal and distal tibia fractures). After one or several reaming passages, a nail of adapted length and 0.5 mm to 1.0 mm less diameter than the latest reamer head is chosen. Under fluoroscopic control, the nail is inserted over the drill guide. Once its tip passed the fracture area and reaches the isthmus, careful hammer blows can be used to drive the nail into its definitive position. Due to the hammer blows, a diastasis can occur in the fracture area. A diastasis in the fracture area significantly increases the risk of delayed union, nonunion or implant failure. This lengthening must be identified and corrected. Traction is released on the fracture table or distraction on the large distractor of external fixator reduced. Closure of the fracture gap and the correct place of the nail are consecutively controlled in antero-posterior and lateral fluoroscopic views. Especially is the ideal position of the head-and-neck screws, which will be drilled through the nail later on, analyzed. The drill sleeve(s), which are placed in the corresponding holes of the targeting device, must point towards the femoral neck and head. The nail is placed more distally or pulled towards more proximally, if needed. The drill guide is removed and distal (free hand) interlocking performed. For proximal femoral fractures, distal double interlocking is sufficient. The tight connection between the nail and the inner cortex at the isthmus gives additional stability (34).

Finally, the nail is interlocked proximally. Two angular stable interlocking screws are inserted below each other into the femoral neck. Ideally, the screws pass through the central part of the femoral neck in the lateral view. The screws end between 0.5 mm and 1 mm below the articular surface of the femoral head, where they have good grip in the dense subchondral bone. After removal of the targeting device, an end cap is screwed in the base of the nail. It protects the inner thread of the nail and makes later nail removal easier (9).

Distal femur fractures have the same gender and age distribution as their proximal counterparts. There is a peak incidence in young men and in older women. Distal femoral fractures in young men are the result of high-energy accidents, they are comminuted, and there is frequent intra-articular involvement and severe soft-tissue damage. In older women, the trauma mechanism has a low energy; the fracture type is simpler mostly being an extra-articular spiral fracture without or with limited soft tissue damage. Due to the pulling force of the gastrocnemius muscles, which are attached to the distal fracture fragment, there is a tendency of recurvatum (apex posterior deformity) in the fracture (31).

There are definite advantages of intramedullary nailing of distal femoral fractures. The technique of stabilization is less invasive, the implant is localized in the weight bearing axis of the femur, and the bone-implant construct has no absolute stability, which enables a secondary fracture healing. Stability is high enough to allow immediate postoperative active motion and partial weight bearing. Challenges of the procedure are restoring the axis, length and rotation of the broken femur and inserting the implant in an ideal position within the medullary canal of the femur. Moreover, malalignment has to be avoided (19).

The patient is placed in supine position on the operation table. Distal femur and knee, which is flexed up to 30°, are supported by a pillow. In this position, the recurvatum in the fracture is corrected and there is an easy access to the joint for nail insertion. The broken distal femur is aligned by longitudinal traction. Closed reduction is easier than in proximal femur fractures (Fig. 4a–f). Any

Fig. 4a–f. a – AP view of the right distal femur and knee of a 58-year-old male after fall with bicycle. There is a spiral fracture with wedge fragment in the distal third of the shaft; b – Lateral view of the right distal femur and knee. The typical rotation of the distal fragment towards dorsally due to pull of the gastrocnemius muscles is visible; c – AP view of the right distal femur and knee after retrograde intramedullary nailing with DFN. The patient has been placed on a radiolucent table. With manual longitudinal traction on the leg and positioning of the distal femur on a pillow, axial alignment could be restored and recurvatum corrected. A long nail, which passes the isthmus, has been inserted. Distal interlocking with spiral blade and static interlocking screw, proximal interlocking with two screws; d – Lateral view of the right distal femur and knee. The fracture gaps are closed and perfect alignment is achieved; e – AP view of the right distal femur and knee after one year. There is abundant callus formation, which proves that intramedullary nailing did not create absolute stability; f – Lateral view of the right distal femur and knee after one year. The fracture is completely healed.

Fig. 5a–d. a – AP view of the right distal femur and knee of an 83-year-old female after a domestic fall. There is a long spiral fracture in the distal half of the femur; b – Lateral view of the right distal femur and knee. Good alignment of the fracture fragments without recurvatum can be seen; c – AP view of the right distal femur and knee one year after trauma. The operation has been performed on a radiolucent table with soft support of the distal femur. No acceptable reduction could be achieved by closed manipulation of the fragments. The spiral fracture was exposed, reduced and fixed with two cerclage wires. A long nail, which passes the isthmus, is chosen. Due to high stability in the fracture gap, there is limited callus formation; d – Lateral view of the right distal femur and knee after one year. On the one-year AP and lateral controls, bridging callus is visible on the medial, lateral and posterior cortex.

axis deviation and rotational malalignment must be avoided. If an acceptable reduction cannot be achieved by closed means, percutaneous or minimal invasive auxiliary tools should be used: Schanz' screws in both main fracture fragments in case of transverse fractures, pointed reduction forceps or cerclage wire in case of spiral fractures (Fig. 5a–d). A large distractor or external fixator with lateral-to-medial screws in the proximal and distal femur can be used to provisionally protect the reduction. The fracture should always be reduced before the nailing procedure starts (18).

The central axis of the femoral shaft is identified with the "cable technique". The cable of the electrocautery is placed over the skin of the reduced distal femur. Its position is controlled with antero-posterior fluoroscopy and adjusted until it is overlying the central axis of the medullary canal. A skin incision is made just parallel to the cable at the level of the patellar tendon. The deeper layers are split medial to the tendon. The knee joint is opened and the intercondylar area located. Under lateral fluoroscopic view, the Blumensaat's line is identified (12). The entry portal for the retrograde nail is just in front of the Blumensaat's line and in the middle of the intercondylar area. Care should be taken to prevent any damage to the insertion of the posterior cruciate ligament. A small entry portal is made with the tip of an awl. The drill guide is entered through this entry portal and forwarded towards proximally. Special attention is needed to ensure that the drill guide is located in the center of the condylar block and points straight towards the center of the isthmus. The correct location of the drill guide is controlled in antero-posterior and lateral fluoroscopic view. Intramedullary blocking screws (poller screws) can be used to prevent the drill guide taking the wrong direction or to correct malalign-

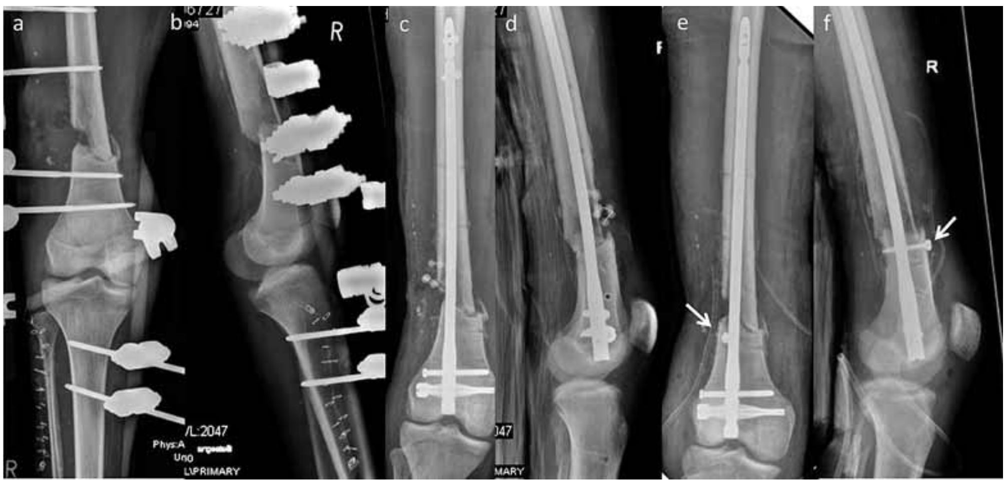


Fig. 6a–f. a – AP view of right distal femur and proximal lower leg of third degree open distal femur fracture with bone defect in a 23-year-old male patient after blast injury. The fracture and soft tissue damage were primarily treated with a joint bridging external fixator. A lateral fasciotomy of the lower leg has been performed; b – Lateral view of right distal femur and proximal tibia shows displacement and angulation in the distal femur fracture; c – AP view of the distal femur and knee joint after retrograde intramedullary nailing of the distal femur fracture. A valgus angulation in the fracture is visible. The soft tissues at the fracture area have been debrided and treated with a short PMMA-chain; d – Lateral view of the distal femur and knee joint. Showing minimal antecurvation in the fracture area; e – AP view of the distal femur and knee joint after correction of the valgus angulation with a poller screw (white arrow). The spiral blade and distal interlocking screw have been removed, the angulation corrected with a pointed reduction forceps and a poller screw, which is placed lateral to the nail in the distal fragment. Finally, the spiral blade and interlocking screw have been reinserted; f – Lateral view of the distal femur and knee joint. The poller screw (white arrow) is inserted from anterior to posterior and lateral to the nail.

ment (Fig. 6a–f) (see also below, proximal tibia fractures) (32). It is recommended to push the drill guide as far as the proximal femur. This enables insertion of long nails after careful reaming of the medullary canal. Longer nails are in tight connection with the inner cortex at the isthmus. They therefore realize a higher stability and prevent toggling of the nail and the distal fragment at the proximal interlocking screws (2).

When an intra-articular extension of the distal femur fracture exists, it needs anatomic reduction and stable fixation first. The knee joint has to be opened and the fracture fragments directly reduced by conventional means. Lateral-to-medial or anterior-to-posterior lag screws are located outside the trajectory of the nail and its distal interlocking screws. Once the condylar block has been restored, the metaphyseal or distal femur fracture is reduced as pointed out above.

Metaphyseal fractures of the tibia

Proximal tibia fractures only count for 7–10% of tibia fractures. They mostly are the result of a high energy accident and combined with severe closed or open soft tissue damage. The fracture pattern varies from simple to multifragmental (26). Proximal tibia fractures are difficult for nailing. The most important complications are iatrogenic fractures, axis deviation, delayed union, nonunion and implant failure. In some case series is the incidence of complications so high, that the procedure itself is questioned for these fractures (13). Nevertheless, nailing has distinct advantages over plating or external fixation. The implant is completely intra-osseous and located in the weight-bearing axis of the lower extremity. The challenges of nailing of proximal tibia fractures are inserting a rigid implant through an eccentric entry portal without causing additional, iatrogenic damage and avoiding any axial deformity.

As in proximal and distal femur fractures, proximal tibia fractures also need reduction before the nailing procedure is started. Due to the attachment of muscles and tendons, the typical displacement of a proximal tibia fracture is in antecurvation and valgus. If there is an extension of the fracture into the joint, it must be reduced and fixed first. Lag screws and/or a small plate are placed in such a way that they do not hinder later nail insertion and interlocking (Fig. 7a–n). The patient is placed in supine position on a radiolucent table or on a fracture table. When a fracture table is used, the knee joint is fixed and flexed in 90° over a post and longitudinal traction is carried out on the foot with a leather booth or a calcaneal pin. We do not recommend using a fracture table because of two reasons. Firstly, the fracture is seldom perfectly reduced by traction and some axis deviation remains. Secondly, the knee joint is fixed in 90° of flexion, which hinders free access to the ideal entry portal of the nail. We prefer using a large distractor or external fixator with medial-to-lateral pins in the very proximal and distal tibia instead. They should not hinder later nail insertion (21).

Once provisional stability is obtained with the large distractor, fine-tuning of the fracture is done. The proximal and distal fragments of transverse fractures are aligned with the help of Schanz' screws. A pointed reduction forceps is used in oblique and spiral fractures. They are placed percutaneously through small skin incisions or a through a larger, but limited skin incision at fracture level. Reduction can be secured by the insertion of one or several lag screws or K-wires. They have to be placed outside the trajectory of the nail. Cerclage wiring is not recommended in the proximal tibia. Due to the vicinity of nerves and vessels, there is a high risk of irreversible damage to these structures (27).

Once a correct reduction has been achieved in the antero-posterior and lateral fluoroscopic views, the nailing procedure is started. For optimal nail placement, several prerequisites have to be fulfilled. The entry portal for the nail must be line with the central axis of the endomedullary canal in the strict antero-posterior fluoroscopic view. Mostly, it is located just anterior to the lateral intercondylar eminence of the tibia plateau. In lateral fluoroscopic view, the entry portal is at the edge between the tibia plateau and the anterior cortex of the proximal tibia. The entry portal is chosen as proximal as possible to have the longest trajectory as possible for the nail in the proximal tibia fragment. This area is called "safe zone" and located between the anterior horn of the medial and lateral meniscus, behind the patellar ligament (15). An entry portal, which is made too lateral or too medial, will inevitably lead to varus resp. valgus malalignment. An entry portal, which is made too anterior, will inevitably lead to an antecurvation in the facture (apex anterior malalignment). There is no possibility for correction of any malalignment, once the nail has been inserted (14).

There are several alternatives for the surgical access to the "safe zone". The classical approach is an infrapatellar incision through or lateral of the patellar tendon. The area can easily be reached, but the path is not in line with the axis of the medullary canal. Only when the knee joint is flexed 110°or more, the patella is out of the entry path of the nail. With this knee flexion, the leg must be held stable by an assistant doctor. Moreover, there is a risk of loss of reduction, when the knee joint is brought into far flexion and fluoroscopic control is only possible in the lateral view. This makes the nailing procedure of proximal tibia fractures a challenging procedure.

Recently, a suprapatellar approach for proximal tibia nailing has been described. The trajectory for the nail is developed with a suprapatellar skin incision and a longitudinal split of the quadriceps tendon. The trajectory then runs behind the patella in the intercondylar groove. When the knee joint has 30° of flexion, the soft spot at the tibia plateau can then easily be reached with a straight drill guide. A knee flexion of 30° has major advantages. The lower leg is put on a firm pillow, which is placed on the operation table. In this position, the leg is stable and precise reduction of the fracture is facilitated. The leg does not need further manipulation for nail insertion. Antero-posterior and lateral fluoroscopic controls are possible during the whole procedure. A special set of instruments is needed for protection of the cartilage of the patella and the femoral condyles. The suprapatellar approach is increasingly used for nailing of proximal

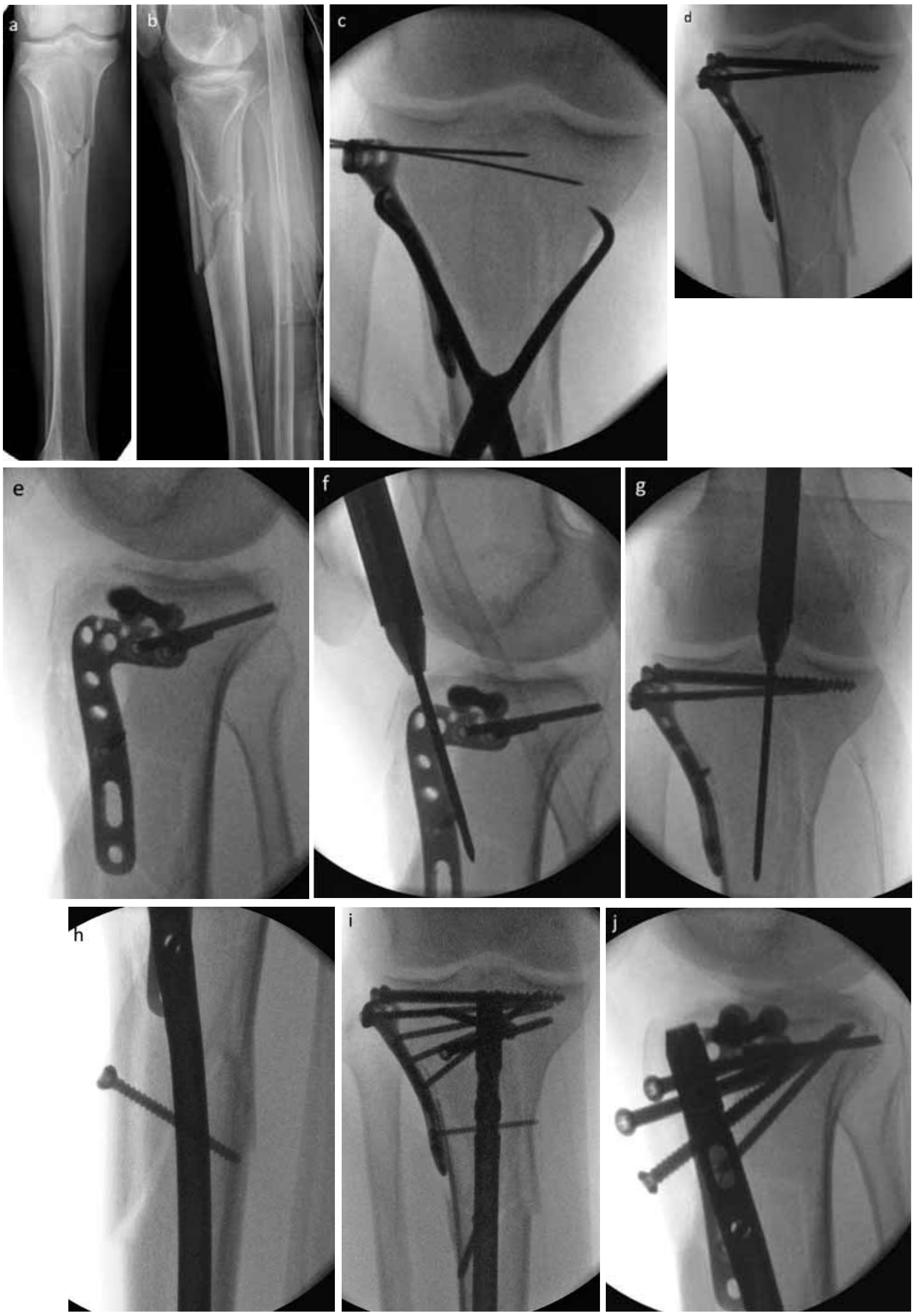


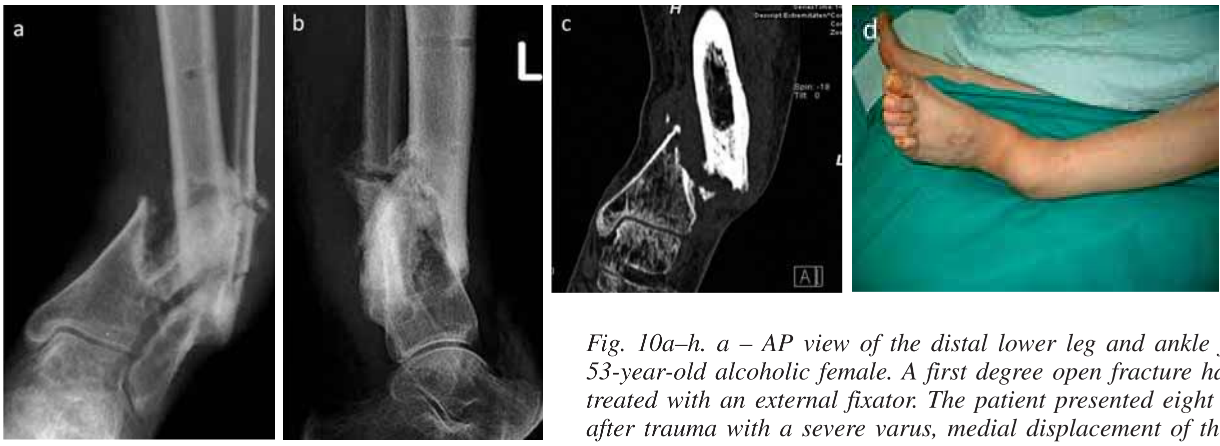
Fig. 7a–n.
a – AP view of the right lower leg and knee joint of a 47-year-old male after direct blow on the lower leg due to a working accident. There is a comminuted fracture at the proximal third of the tibia with extension into the lateral condyle of the tibial plateau; b – Lateral view of the right lower leg and knee joint after trauma showing the fracture comminution. There is a good fracture alignment both in the AP and lateral views; c – Intra-operative fluoroscopic views showing the different steps of reduction and intramedullary nailing. AP view of the tibia plateau. Reduction of the intra-articular fracture with a pointed reduction clamp and provisional K-wires. Application of a short L-shaped plate through a short anterolateral approach; d – AP view of the tibia plateau. Situation after stabilization of the intra-articular fracture component with two cancellous screws and a short anterolateral L-plate. The distal screw of the plate is monocortical to prevent a conflict of the screw with the nail, which will be inserted subsequently; e – Lateral view of the tibia plateau. The two proximal screws of the L-plate have been inserted posteriorly in order to prevent a conflict with the nail and proximal interlocking screws; f – Lateral view of the knee joint. Opening of the entry portal through a suprapatellar approach. The trocar is situated behind the patella and in front of the femoral condyles; g – AP view of the knee joint. Trocar and drill guide, the last being introduced in the proximal tibia are visible; h – Lateral view of the proximal lower leg. The tibia fracture has been reduced with a pointed reduction forceps and fixed with a lag screw, which is inserted perpendicular to the fracture plane. The nail has been introduced over the drill guide and passes the fracture area; i – AP view of the tibia plateau and proximal tibia. The nail has been locked proximally with three interlocking screws. The monocortical screw of the L-plate is removed and further longer angular stable screws inserted through the plate. The lag screw is visible in the proximal shaft just lateral to the nail; j – Lateral view of the tibial plateau showing two cancellous screws just below the articular surface, three interlocking screws through the nail and the L-plate with several angular stable screws; k – AP view of the lower leg one year after intramedullary nailing. There is a complete healing of the fractures and excellent alignment of the lower leg; l – Lateral view of the lower leg showing complete healing with perfect alignment; m – AP view of the lower leg after metal removal; n – Lateral view of the lower leg after metal removal.

Fig. 8a–n.
a – AP view of the left lower leg and knee joint of a 55-year-old male bicyclist after collision with a motorcar; There is a segmental fracture of the tibia with the proximal fracture being in the proximal third of the shaft; b – AP view of the lower leg and ankle joint is showing the distal extension of the segmental tibia fracture; c – Lateral view of the lower leg and knee joint after trauma. d – Lateral view of the lower leg and ankle joint after trauma; e – Intra-operative fluoroscopic views showing the different steps of reduction and intramedullary nailing. AP view of the knee joint after the insertion of a Schanz' screw just below the articular surface of the tibial plateau; f – AP view of the distal lower leg after insertion of two Schanz' screws above the ankle joint; g – Lateral view of the knee joint. A suprapatellar entry path for nail insertion has been chosen. The trocar is situated behind the patella and in front of the femoral condyles. The drill guide is inserted in the proximal tibia; h – AP view of the knee joint. The drill guide is pointing towards the lateral cortex of the proximal tibia; i – AP view of the proximal lower leg. After insertion of an anteroposterior poller screw at the lateral side of the proximal fracture fragment, the tip of the drill guide is pointing towards more medial. The tip of the nail is introduced in the proximal fracture fragment; j – AP view of the proximal lower leg. The tip of the nail is passing the poller screw medially and takes the correct trajectory towards distal; k – Lateral view of the proximal lower leg. A second poller screw, which is inserted from medial to lateral in the posterior part of the proximal fragment, avoids antecurvation (apex anterior malalignment) of this proximal fragment; l – AP view of the distal lower leg and ankle joint is showing the central location of the nail tip in the distal fragment; m – AP view of the lower leg after intramedullary nailing. Triple interlocking proximal and triple interlocking distal; n – Lateral view of the lower leg. The poller screws, which are located beside the nail, have been left in place.

Fig. 9a–d.
a – AP view of the lower leg of a 56-year-old female after sports accident. There is a comminuted isolated tibia fracture in the distal fifth of the shaft; b – Lateral view after trauma; c – AP view after intramedullary nailing. The tip of the nail is in the center of the distal metaphysis. The short distal fragment has been interlocked three times. Double proximal interlocking is sufficient; d – Lateral view of the lower leg after intramedullary nailing.

tibia fractures (Fig. 7a–n) (6). There are only few data on mid- to long-term outcome of suprapatellar nailing available. In the study of Sanders et al., alignment, union rate and knee function of 36 patients was excellent. Moreover, there was no knee pain, which is often seen in standard nailing (29).

We recommend always using a drill guide for nailing of metaphyseal fractures. Using a drill guide implicates using cannulated nails.



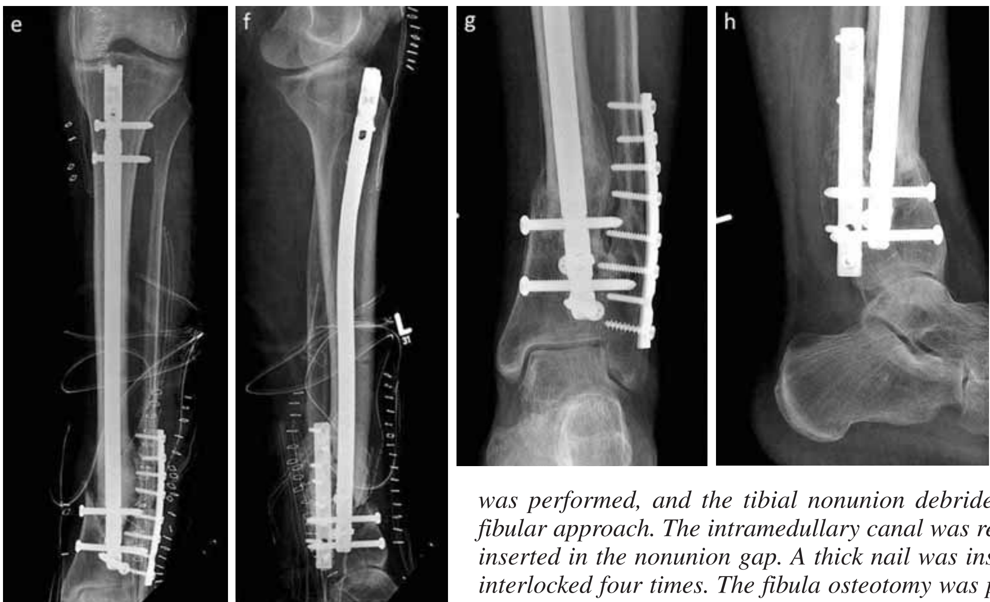


Fig. 10a–h. a – AP view of the distal lower leg and ankle joint of 53-year-old alcoholic female. A first degree open fracture had been treated with an external fixator. The patient presented eight months after trauma with a severe varus, medial displacement of the distal fracture fragment, tibial nonunion; and shortening. The wound was healed; there were no signs of infection; b – Lateral view of the distal lower leg and ankle joint is showing a retrocurvation (apex posterior malalignment) in the fracture area; c – Coronal CT-cut through the nonunion. d – Clinical picture of the lower leg and foot is showing severe malalignment; e – AP view of the lower leg after intramedullary nailing. An osteotomy of the fibula was performed, and the tibial nonunion debrided and realigned through the fibular approach. The intramedullary canal was reamed and the reaming debris inserted in the nonunion gap. A thick nail was inserted and the distal fragment interlocked four times. The fibula osteotomy was plated with a thick plate. Nice realignment was achieved; f – Lateral view of the lower leg after intramedullary nailing; g – AP view of the distal lower leg and ankle joint after 6 months is showing fracture healing without any secondary displacement; h – Lateral view of the distal lower leg and ankle joint is showing healing in slight residual recurvation.

The use of a drill guide has several distinct advantages. When the drill guide is inserted through the correct entry portal and the tip of the guide is placed in the center of the distal metaphyseal block, the nail will follow the trajectory of the drill guide during insertion and eventually arrive at its optimal position. The drill guide enables gentle drilling of the endomedullary canal. The reaming debris has an osteogenic potential and a nail with a larger diameter can be chosen, which enhances stability of the bone-implant construct (1, 27).

With the help of intramedullary blocking screws (poller screws), the wide medullary space of the proximal tibia can artificially be narrowed and an isthmus created. Poller screws force drill guide and nail to take the desired pathway and block an eccentric pathway. They prevent the occurrence of axis deviation during nail insertion. The screws have to be placed on the opposite side of the deformity, which is prevented. If an apex anterior deformity (antecurvation) needs to be prevented, a medial-to-lateral poller screw is inserted in the posterior half of the medullary canal of the proximal fragment. If an apex medialis deformity (valgus) needs to be prevented, the poller screw is inserted from anterior to posterior in the lateral part of the medullary canal, in case an apex lateralis deformity (varus) needs to be inhibited, the poller screw is inserted from anterior to posterior in the medial part of the medullary canal of the proximal fragment (Fig. 8a–n) (11, 32, 33). The poller screw can remain in place after nail insertion and interlocking, it also can be removed. Instead of screws, Steinmann pins can also be used as "poller pins".

It is recommended performing multiple interlocking of the short fracture fragment in different planes. Last generation nails allow interlocking very near to the tibia plateau in the antero-posterior and both oblique directions. The screws provide a high resistance against axial, bending and rotation forces applied on the lower extremity (Fig. 7j). At least three screws should be used (7). In nail designs, which allow multiple interlocking near the nail base, additional medial-to-lateral interlocking screws can be inserted as well. Distal double interlocking at the tip of the nail is sufficient. The nail itself provides additional stability in the distal fragment when it has direct contact with the inner cortex at the isthmus.

Distal tibia fractures are more frequent than proximal ones. The fracture pattern is complex in case of high-energy trauma. There also frequently is damage to the soft tissue envelope, especially on the medial side. Spiral fracture types are the result of rotational injuries (e.g. fall while skiing or fall at home in the elderly patient). Also in distal tibia fractures, there are distinct advantages of intramedullary nailing (5). An extension of the distal tibia fracture into the tibia pilon must be ruled out and addressed surgically, if present. Lag screws must be placed outside of the trajectory of the nail.

The principles and technique of intramedullary nailing are similar to the procedure used in proximal tibia fractures (4). The fracture must be reduced before the nailing procedure can start. For precise reduction, we recommend using the same tools as in proximal tibia fractures. A large distractor or external fixator aligns the broken leg and brings stability in the fracture area. Pointed reduction forceps, lag screws and poller screws can be used before or during nail insertion. Cerclage wiring must be avoided because of the high risk of damage of the neurovascular structures. The correct entry portal at the proximal tibia must be chosen with care, but it is not that critical than in nailing of proximal tibia fractures. A suprapatellar nailing is not necessary. It is recommended always using a drill guide and performing gentle reaming for the same reasons as in nailing of proximal tibia fractures.

Most important is a correct and precise placement of the tip of the drill guide in the distal tibia segment. This must be controlled in antero-posterior and lateral fluoroscopic views. When the nail follows the same trajectory during its insertion, it will finally come into its correct position. The tip of the nail must be interlocked with three interlocking screws. The screws ideally are placed in different planes: medio-lateral, antero-posterior and oblique (Fig. 9a–d) (4, 20). There still is controversy concerning the need of fixation of the concomitant fibula fracture in distal third tibia fractures. We recommend additionally stabilizing the fracture of the fibula with plate and screws, when the fracture is located at the same level of the tibia fracture. The fibula osteosynthesis adds to the overall stability and correctly restores the anatomy of the ankle joint (Fig. 10a–h) (3, 4, 17).

Conclusions

Intramedullary nailing of metaphyseal fractures of femur and tibia is more difficult than nailing of diaphyseal fractures. Because of its important biological and biomechanical advantages, it is worthwhile to consider intramedullary nailing as an alternative to other stabilization techniques for these fractures. The main challenge is reducing the fracture prior to the nailing procedure and securing this reduction during nail insertion and interlocking. Typical displacement of fracture fragments of the proximal femur, distal femur or proximal tibia must be corrected. Different tools and techniques are available for fracture reduction. The choice of the correct entry portal is of utmost importance for optimal position of the nail. Using a drilling guide enables gentle reaming, correct positioning of the nail and using a larger nail for higher stability. The short fracture fragment needs angular stable or multiple interlocking in different planes to counteract every kind of loading on the extremity. With the nail in its exact position, with perfect axial alignment and good fracture approximation, we can allow early active motion and partial weight bearing. We also can expect an uneventful healing and a good functional outcome. Intramedullary nailing of metaphyseal fractures of the lower extremity requires a thorough preoperative analysis of the fracture form and individual planning of the steps needed for fracture reduction and uneventful nail insertion. Nailing of metaphyseal fractures is more surgical art than surgical technique.

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