Femoral Shaft Fractures in Adults: Treatment Options and Controversies

Zlomeniny diafýzy femuru u dospělých: možnosti léčení a kontroverze

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SUMMARY

Antegrade reamed femoral nailing via the piriformis entry point is the technique of choice in treating femoral shaft fractures, with retrograde nailing as an alternative. The supine position is favored to reduce complications, especially rotational malalignment. With navigation and robotic assistance fracture reduction can be supported and the rate of rotational, axis and length malalignement can potentially further reduced.

Careful reaming is the procedure of choice to optimize bony healing and reduce systemic and local complications. In multiply injured patients reamed nailing can be safely integrated in the DCO- or ETC-concept and can be performed in the majority of patients, even when additional severe chest and head injuries are present. Initial resuscitation should focus on general stabilization before definitive femur fixation.

Plate osteosynthesis of the femur can be an option in selected patients.

INTRODUCTION

Non-operative treatment of femoral shaft fractures in adults is an exception. With the available surgical stabilization techniques, numerous studies support the advantage of surgical therapy in terms of morbidity, mortality and functional outcome.

Femoral shaft fractures are typically an emergency indication as delayed fracture stabilization is associated with an increased morbidity, and a longer hospitalization time (9).

In a recent analysis comparing different treatment options in femoral shaft fractures, it could be clearly stated that intramedullary fixation of femoral shaft fractures was associated with the lowest complication rates and loss of reduction rates compared to external fixation or plating strategies (41). Therefore, femoral nailing is the overall "gold standard" in treating femoral shaft fractures (18).

The concept of damage control orthopaedics especially treating femoral fractures in polytraumatized patients is well established, but clear indicators, which patients benefit from this approach, are missing. Additionally, since more than two decades, there is a controversy regarding reaming or not reaming and antegrade or retrograde nailing. Especially for antegrade nailing, discussion is still present which patient position is optimal and which entry point for nailing should be used. In some patients, even nailing is impossible and therefore a plan B option should be considered with plating.

Therefore, this paper is dealing with these topics in treating femoral shaft fractures and an overview of the present literature on these controversies is presented.

PATHOPHYSIOLOGY OF THE INJURY

Even isolated femur fractures are associated with an increased risk of post-traumatic complications due to the high-energy mechanism with significant bony and additional soft-tissue injury resulting in substantial blood. The soft-tissue injury primary can initiate a local inflammatory response with release of zytokines which can trigger a secondary systemic inflammatory response syndrome (SIRS) (24).

In the context of multiple trauma, the additional femur fracture is of major importance as patients with bilateral femur fractures have a significantly higher mortality rate than with unilateral injury (16% versus 4%, (33)).

The trauma-induced inflammatory response is not only determined by the bone or soft-tissue injury. Other body regions contribute significantly to the local synthesis and systemic release inflammatory mediators. Especially the lungs are a significant source of these mediators leading to a potential risk of a systemic inflammatory response syndrome (SIRS) (38).

However, in addition to the fracture-induced pathophysiological response („first hit“), surgery can cause another release of inflammatory mediators („second hit“) (24, 39) which can increase the rate of systemic complications (ARDS, MODS) (17).

The extent of this „second hit“ is potentially dependent on the type of primary fixation as initial definitive treatment of femoral fractures (“Early Total Care”, ETC), e.g. reamed femoral nailing, can lead to a significantly increase of the inflammatory response with increased cytokine levels (IL-6), activation of granulocytes, endothelial cells and pulmonary permeability (17).

Pape et al. identified a special subgroup of patients with a higher risk of developing systemic complications („borderline patients „), where the stabilization method and the duration of surgery affected the outcome (40). Therefore, minimization of the initial surgical trauma by primary temporary stabilization with external fixation techniques is thaught to result in less complications and better prognosis: „Damage Control Orthopedics“ Concept (DCO).

Controversy 1: Damage Control Orthopaedics (DCO) vs. Early Total Care (ETC)

In the 70s and 80s several studies supported early definitive femoral fracture treatment for reducing associated pulmonary complications, a decrease of ventilation time, reduced incidence of MOF, reduced mortality and length of hospital stay (LOS) (in: (8)). The evolved concept of early definitive care included early stabilization (within 24 hours) and definitive stabilization (of all long bone fractures) in polytrauma patients.

In the early 90ies the pathophysiological consequences of primary intramedullary nailing was questioned as several complications arised in selected patient groups. Pape et al. reported on patients who had early (within 24 hours of injury) reamed intermedullary nailing of the femur and concomitant severe pulmonary injury what resulted in an increased incidence of ARDS and death (38). Additional occult hemorraghe could be identified as another potential risk factor with a twofold higher incidence of postoperative complications (13). Further risk factors were the additional presense of head and chest injury (26, 38). This lead to the devlopment of the pathophysiological based DCO-concept, reducing the “second hit” trauma in patients at risk. Therefore, this latter group includes multiply injured patients with an ISS of >20 and additional chest trauma, multiply injured patients with hemorrhagic shock and an initial systolic blood pressure of <90 mm Hg, patients with bilateral pulmonary contusion or an initial mean pulmonary artery pressure of >24 mm Hg (8). An aggressive resuscitation protocol with hemorrhage control, frequent reevaulation and stabilization of the physiology was recommended as it could be stated that multiple trauma patients with primary intramedullary nailing had also a higher risk to develop the systemic inflammatory response syndrome (SIRS) (23).

Consequently, comparable studies analyzed the effect of DCO versus ETC. Scalea et al. retrospectively compared 43 patients initially treated with external fixation with 284 patients treated with primary intramedullary nailing (IMN). The external fixation group had a higher injury severity, required more fluids and blood transfusion and had more severe head injuries. Overall, a lower complication rate was observed, but LOS was increased (44). Analyzing patients with additional head and chest injuries, it was found that the rates of ARDS, pneumonia and LOS were lowest in patients fixed within 24h, whereas fixation between the 2nd and 5th day posttrauma were associated with a significant increase of pulmonary complications (11). Tuttle et al. found that after DCO treatment, despite a significantly shorter operative time less blood loss, no significant difference was seen reagrding pulmonary complications, multiple organ failure (MOF) and LOS (49).

In head trauma patients, a staged protocol depending on the severity of the head injury is recommended (15). The EAST Study group stated, that “there is no compelling evidence that early long bone stabilization in mild, moderate, or severe brain injured patients or patients with chest trauma either enhances or worsens outcome” {Dunham, 2001 #55}. An individual approach was recommended according to the patient‘s clinical condition

Recently, in a review it was stated, that ETC can safely be performed in patients with minor head injury and/or normal craniocerebral CT scan, whereas DCO is clearly recommended in patients with a Glasgow Coma Scale (GCS) ≤8. In moderate head injury patients (GCS 9–12), DCO should be considered (15).

Presently, there is no clear evidence that ETC leads to increased complications, but still a subgroup exists which may benefit from DCO. Primary aggressive resuscitation before IMN is recommended to avoid complications. Then, even patients with significant chest trauma can safely be treated by initial femoral nailing and an additionall head injury is also no contraindication for ETC.

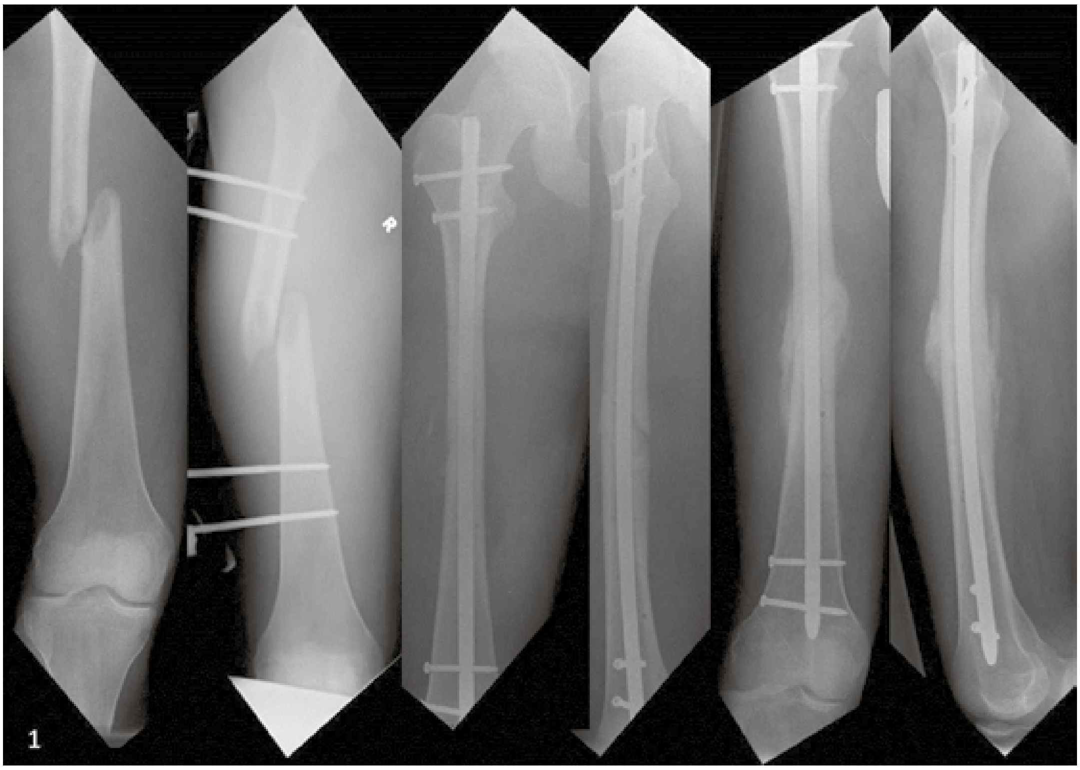

Fig. 1. 28-year-old male after MVA with severe chest and head trauma and an additional femur shaft fracture. Emergency stabilization was performed by temporary external fixation with an adequate restoration of the axis. After stabilization of the physiological status, definitive antegrade unreamed nailing was performed on day 10 postinjury. After 3 month uneventful healing of the femur fracture had occurred.

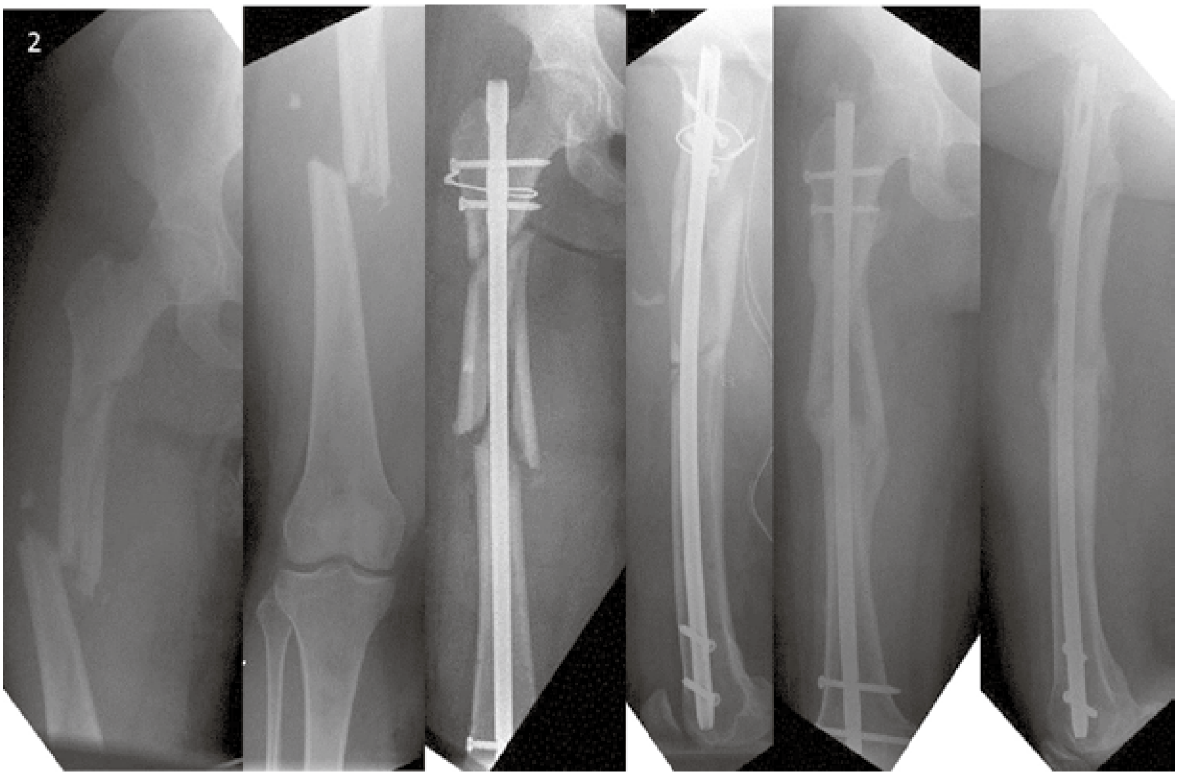

Fig. 2. 34-year-old male after MVA. Segmental right isolated femoral shaft fracture. Unreamed antegrade unreamed nailing was performed with protection of the proximal fragment with cerclage wires. Full weight bearing was possible after 9 weeks. At latest follow-up, 9 month after the injury, uneventful healing of the femur fracture had occurred.

TREATMENT

Today intramedullary nailing of femoral shaft fractures is the Gold-Standard of treatment. In a recent analysis comparing different treatment options in femoral shaft fractures, it could be clearly stated that intramedullary fixation was associated with the lowest complication rates and loss of reduction rates compared to external fixation or plating strategies (41).

Conservative treatment

Conservative treatment of femoral shaft fractures in adults is only exceptional as surgical stabilization techniques offer significant advantages in terms of morbidity, mortality and functional outcome (18). Only in presense of general contraindications for anesthesia and surgery traction treatment or even cast treatment can be initiated.

Operative treatment

Operative treatment has the advantage of better results regarding morbidity, mortality and functional outcome. Femoral shaft fractures are an emergency indication and should be promptly stabilized as delayed stabilization is associated with increased morbidity, particularly in the lungs and a longer hospital stay (9).

Intramedullary nailing

Intramedullary nailing (IMN) is the Gold-Standard in treating patients with femoral shaft fractures (Figs 1 and 2). Today, still several controversies exists. The main discussion is on the approach of retrograde versus antegrade nailing. In antegrade nailing, which is the standard for the majority of surgeons, the optimal entry point as well as the optimal positioning of the patient is still under discussion. In contrast, the pendula of the reaming debate is clearly swingig to reamed nailing. Therefore, an overview of these controversies will be presented.

Controversy 2: Antegrade vs. retrograde nailing

Antegrade femoral nailing resulted in good clinical results and a union rate of up to 99% (52) and was therefore recommended as gold standard in femoral shaft fracture treatment (18). Recent studies still show a high number of bony healing with 97,8% and a low complication rate. Despite standardization of this technique, problems arose like difficulty to identify the optimal starting point especially in obese patients, proximal hip pain, limbing with Trendelenberg gait, decreased abduction strength, trochanteric heterotopic ossifications and varus malalignment in proximal shaft fractures (10).

Therefore, retrograde femoral nailing was proposed as an altenative as positioning, entry point identification and fracture reduction is often easier.

The theoretical disadvantage of intraarticular damage with potential development of posttraumatic knee arthritis is not supported in the literature (in: (18)). No difference with respect to fracture healing rate and knee motion could be found in early comparable studies (47).

The frequency of hip or knee pain depending on the choosen technqiue of antegrade versus retrgrade nailing showed conflicting results. Early results stated that after antegrade nailing significant more patients reported on hip pain, while after retrograde nailing significant more knee pain was reported (47). In a literature review, the mean range of knee motion was 127.6 degrees after retrograde nailing, the rates of knee pain, malunion and re-operations were 24.5, 7.4 and 17.7%, respectively (36).

Additionally, there is a potential risk of septic knee complications (47). Recent data and data from a literature review show that the risk of knee infection is even low with an average of 1.1% after open femoral fractures (35) and 0.18% in diaphyseal fractures (36).

Antegrade nailing is still the technique of choice in treating femoral shaft fractures, but retrograde nailing is an excellent alternative option (Figs 3–5).

Controversy 3: Optimal entry point in antegrade nailing

The classical, conventional entry point for antegrade femoral nailing is the so-called piriformis fossa which lies in line to the medullary canal in both X-ray planes. Problems can arise when approaching too medial with a higer risk of iatrogenic fracture of the femoral neck. In contrast, a too lateral entry point can result in varus deformity, especially in proximal shaft fractures or iatrogenic fractures to the medial cortex (18).

Intraoperative determination of the correct entry point can be difficult due to necessary adduction of the hip for proximal wire insertion with increase of iliotibial tract strain. Therefore, incision of the gluteus medius is often required. The following reaming procedure can lead to significant muscular damage and transfer of intramedullary contents into the muscle (18). Consequently, subsequent development of heterotopic bone formation proximal to the trochanteric tip was described in up to 60% and impairment of hip abduction was found. Due to anatomical variability of the greater trochanter, identification of the entry can be extremely difficult, as in more than 50% of cadaver femora a medial bony overhang was found (21).

Anatomical studies support the risk of damaging muscles, tendons and even the vascular supply to the femoral head when using the piriform fossa approach (4, 14). In conclusion, the with respect to the soft tissue damage, the piriformis entry point shows the worst geometric and biomechanical disadvantages and a more lateral entry point was recommended (14).

In a comparable analysis, lateral nail insertion at the tip of the greater trochanter decreased the risk of damage to the superior gluteal nerve and abductor muscles, resulting in some improved muscle function (3). A further advantage could be found with reduced fluoroscopy time and operation time while clinical and radiological results were identical (43). Therefore, a lateral entry point was stated to be an acceptable alterantive in antegrade nailing (3).

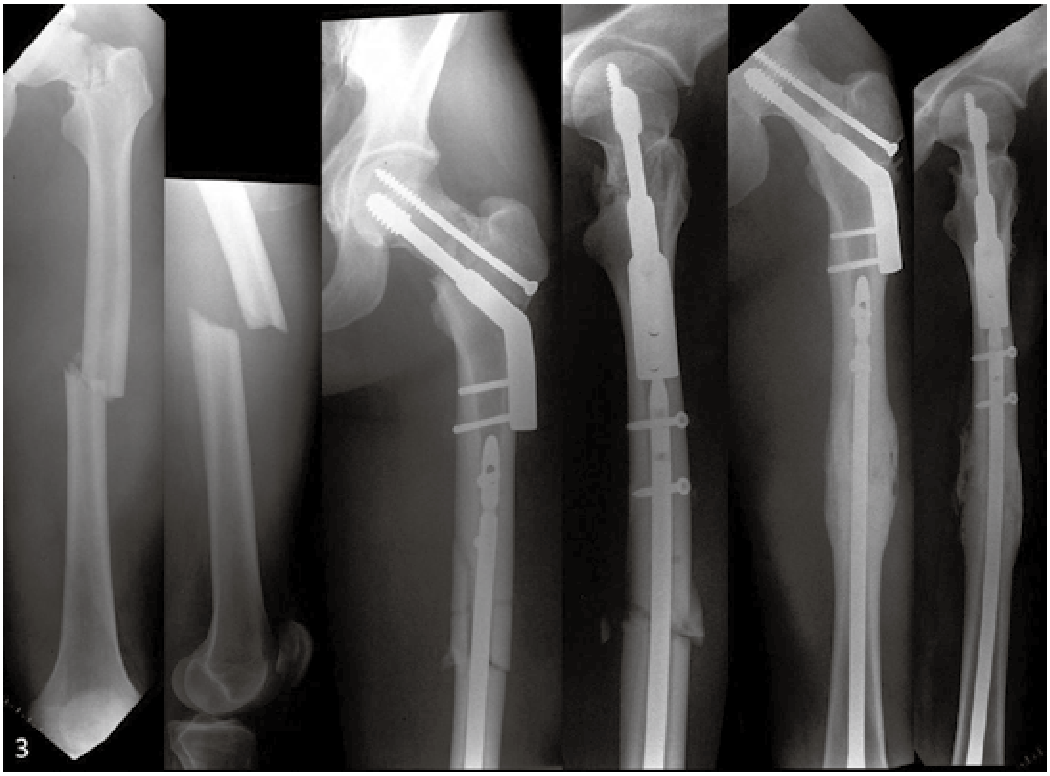

Fig. 3. Combined femoral neck and shaft fracture. Stabilization of the femoral neck fracture with a DHS and an antirotation screw. The shaft fracture therefore was stabilized by retrograde nailing. Healing of both fractures after 4 months.

In contrast, several disadvantages are associated with the lateral entry point. Theoretically, a finite element analysis showed high lateral trochanteric and femoral strains with a potential of iatrogenic fracture of the proximal femur during nail insertion (48). This potential risk was confirmed in a biomechanical study, using the lateral entry point, where highest strains were observed postero-medial at the greater trochanter resulting at least in bony fissures (31). In a cadaveric subtrochanteric fracture model a lateral starting point showed the risk of varus deformity with resulting fracture gapping of the lateral cortex (34). These experimental problems were supported by recent clinical results using a lateral femoral nail, where iatrogenic fractures were reported in 6% (42). Even the overall functional result after lateral femoral nailing is presently not acceptable with a normal walking capacity of 68% and normal active hip flexion in only 45% of (42).

The piriformis entry point of antegrade femoral nail insertion is still the standard.

Controversy 4: Patient positioning in antegrade nailing

During antegrade femoral nailing positioning of the patient is of crucial importance. A poor positioning can significantly impair the operative procedure. Overall, four different positionings are established: supine position with and without traction table and lateral decubitus position with and without traction table (18).

The supine position without a traction table can be simply and fast performed and allows to perform additional operations without re-draping or re-positioning of the patient especially in multiply injured patients.

Fig. 4. Segmental femoral shaft fracture after car accident. Retrograde nailing was performed with adequate reconstruction of length and axis.

The traction table has its main advantage in the permanent and non-fatiguing traction. Potential disadvantages are an increase in surgical preparation time, duration of surgery and anesthesia time and a higher rate of postoperative rotational malalignment (53). Additionally, pudendal nerve lesions and erectile dysfunctions were reported with traction (1). Positioning of the contralateral leg on a Goepel leg holder to allow axial X-ray evaluation can lead to lower leg compartment syndrome, especially, when operation time exceeds 4 hours (46). Therefore, periodical compartment evaluation and movement of the contralateral leg during surgery is recommended (18). Alternatively, mobile positioning of the contralateral leg takes some more effort, but has the advantage of using the femur as a reference for length and rotation. Axial viewing is possible by shortly rasing up the opposite limb.

The lateral decubitus position offers the main advantage of a simpler access to the entry point at the greater trochanter and sterile coverage of the leg is easier. This position can be an option in isolated femur fractures. It can be detrimental in patients with multiple injuries, spinal injuries or severe head or chest injuries, but recently it was shown, that in multiply injured patients reamed IMN in the lateral decubitus position was not associated with an increased risk of mortality (5).

Overall, there are no comparable studies dealing with lateral and supine positions. The main disadvantage of lateral positioning is the lack of femoral rotatory control as orientation of the contralateral limb is not possible. Therefore, the risk of rotational malalignment can be increased. Clinically relevant malrotation (>15°) can be expected to be approximately 20% in unilateral femoral shaft fractures (25) and increases up to 40% in bilateral femoral fractures. The clinical consequence is not finally known as patients are reported to tolerate malalignment relatively well (Gugala, 2011 #90). Internal malrotation is associated with worther results than external malrotation (22). Additionally, the positioning time can be increased.

Supine positioning without traction is the standard in multiply injured patients with less complications (rotational malalignment, traction injury, contralateral compartment syndrome). Lateral decubitus position can be an easy option in isolated femur fractures.

Controversy 5: Reamed vs. unreamed femoral nailing

The local and systemic effects of reamed and unreamed nailing are well described in the literature.

Local effects include change in bone blood flow, local cortical heat generation, medullary pressure changes, soft-tissue side effects and expression of bone marow contents (32).

- reaming of the medullary cavity results in a local, temporary reversible reduction of the endosteal blood flow, which is compensated by an increase of the periosteal blood flow. A change in blood flow orientation from zentrifugal to zentripetal was therefore expected. In cases with an intact soft-tissue envelope reaming was thought to have a positive effect on fracture healing due to an increased circulation within the surrounding soft tissues
- reaming leads to cortical heat generation without development of thermal damage, with the potential risk of segmental heat-induced bone necrosis

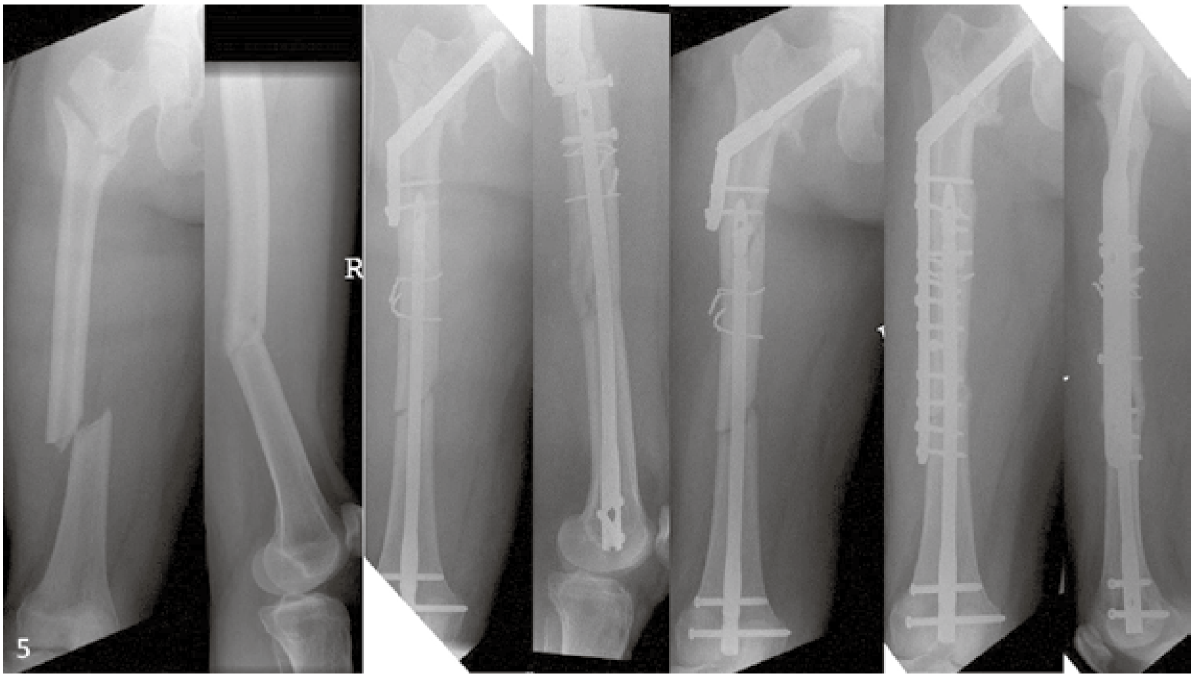

Fig. 5. Multiply injured patient with a two-level femur fracture with a displaced trochanteric fracture and distal shaft fracture. Initial treatment consisted of DHS-osteosynthesis of the proximal fracture and retrograde nailing of the shaft. After 4 weeks subsequent varus deformity developed, leading to an additional plate osteosynthesis on the tension side of the femur. Uneventful healing occurred within the next 3 months.

– both, reamend and unreamend nailing lead to a medullary pressure increase with highest values after reaming
– a further effect of reaming is a pressure increase in muscle compartiments of >30 mm Hg with prompt pressure reduction to normal values developing a compartment syndrome
– the expression of bone marow contents with reaming has an osteoinductive effect and is a potential trigger for bone healing; additionally expression of different growth factors could be identified.

Systemically, reaming can induce a fat embolism syndrome with hemostatic activation, thrombocytes aggregation and an inflammatoric response, which can result in an increase of pulmonary lymphatic flow with development of a pulmonary capillary leakage followed by general pulmonary damage (overview in: (6)).

These side-effects of reaming lead to the development of unreamed nails. There potential advantages are a protection of the endostal circulation, avoidance of thermal cortical injury, a reduced mediator release, shorter operation time and a reduction of intraoperative blood loss.

First clinical results in tibial fractures were promising (overview in (6)) but in a prospective randomized study bony healing time was significantly increased and a higher rate of implant failure was observed (12).

Additional Level 1 studies showed a high rate of fracture complications. In a meta-analysis of prospective randomized studies on femoral fractures unreamed femoral nailing was associated with a significantly higher rate of nonunion and implant failure. With reaming in 1 of 7 patients nonunion and in 1 of 6 patients implant failure can be prevented. Additionally, no increased risk of malunion, pulmonary embolism, compartment syndrome or infection was observed compared to unreamed nailing (7). Additionally, the non-union was 4.5-fold higher than after reaming (45).

Therefore, the long controversy of unreamed or reamed nail insertion of the femur presently favors the reamed technique while even the potential advantages of better bony blood supply and a reduction of infection rates could not be proven (Attal, 2010 #108).

Isolated femoral fractures are best treated with careful reamed intramedullary nailing. In multiply injured patients, according to the DCO-concept, reamed nailing can be safely suggested as the definitive procedure after temporary external fixation.

Technology assistance

The praxis of femoral shaft reduction can be simplyfied and explained as a try to put two cylinders on each other until they cane be stabilized by an intramedullary nail. In the early literature, fluoroscopy times are reported to be above 2.5 minutes (28). Often, redundant movements are necessary under fluoroscopy control in assisting reduction. Computer-assisted nailing based on a fluroscopy-assisted referencing is supposed to enable

Fig. 6. X-ray of the femur in a 45-year-old woman with history of osteomyelitis during childhood. Extreme narrowing of the medullary canal with sclerotic changes preventing potential nailing in case of a fracture.

a proper reduction with permanent visualization of the main fracture fragments without re-visualization under image intensifier control. Another major advantage of navigation can be the direct comparison of femoral anteversion to reduce the rate of postoperative malrotational alignment. Recent experimental studies could support these advantages. In an analysis of 20 cadaveric comminuted femur fractures, fixed with antegrade nailing, computer navigation showed reduced values of leg length differences but identical rotational differences compared to conventional fluoroscopy (27). A further analysis revealed acceptable results with navigation with 7° malrotation (19).

Recently, after simulating navigated reduction and rotational alignment in fractured synthetic bones with good results, clinical testing in 17 patients showed good results with rotational differences to the uninjured side of 5.5° in average and a leg length difference of 2 mm. The main disadvantage was the time to prepare the navigation systrem with 32 minutes and an additional fluoroscopy time of 44 seconds (51). In an ongoing analysis with 40 patients, the set-up was identical but fluoroscopy time could be reduced. Femoral anteversion was restored to a mean difference of 5.4° and a leg length difference of 4 mm (50). Another analysis of 9 femur fractures showed an average malrotation of 6.6° with no patient having a difference of >10° (19).

Recently, robotic assistance was experimentally integrated to support the reduction process (20). First results on plastic bones showed promising results in

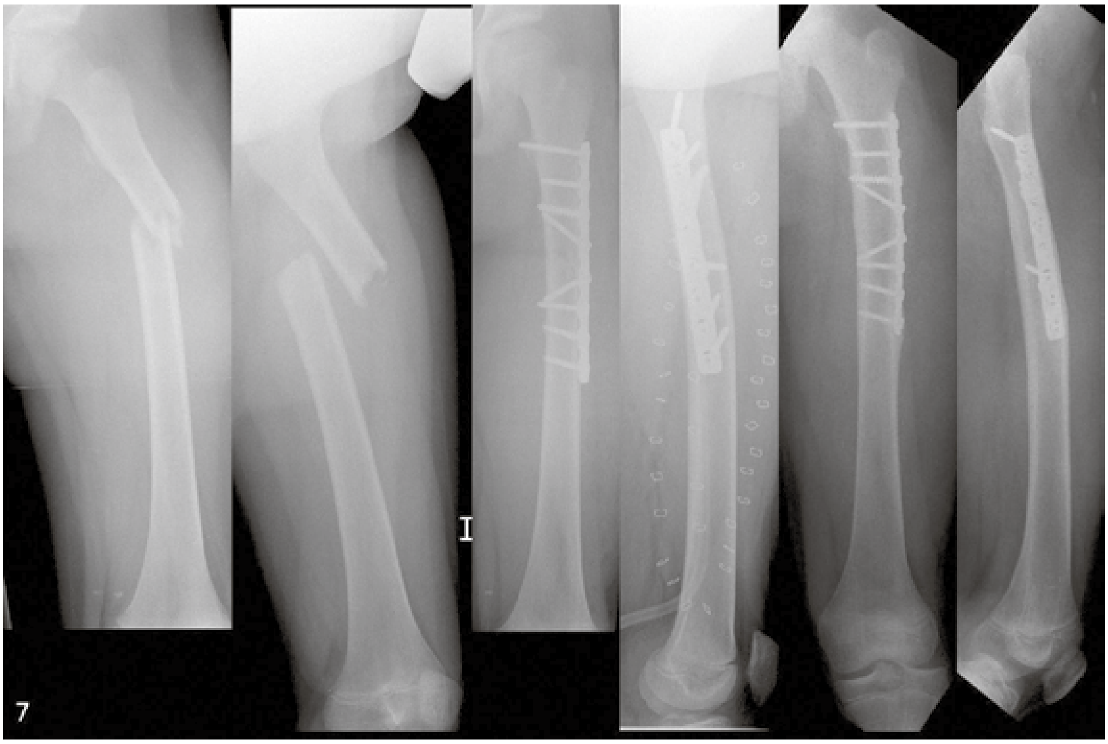

Fig. 7. III° closed femoral shaft fracture with manifest compartment syndrome in a 16-year-old boy. Lateral fasciotomy with subsequent femoral plating was performed as primary treatment. Fracture healing occurred after 4 months.

simple A-type shaft fractures with mean differences of 2° and 2 mm. These results were less good with increasing complexity of the fracture. But even in type B and C fractures rotational differences were <4° in average. Even when using human cadaver femora with intact soft tissue envelopes, similar results could be found, which were superior to manually perfomed reductions. However, the procedure time was lengthened with robotic assistance.

Early results of navigation assistance and robotic assistance in femoral shaft fracture treatment provide encouraging results regarding understanding and optimization of the femoral reduction process and possibly can lead to a reduction of rotational, axis and length malalignement.

The role of plating

The classical concept of plate osteosynthesis according to the AO consists of anatomical reduction, absolute stability, soft-tissue preserving management and early mobilisation is often not possible in femoral shaft fractures due to comminutes fracture areas.

Standard plate-osteosynthesis was for long time stabilization with a large 4.5 mm LC-DCP. The main disadvantage of conventional plating was the extended soft-tissue release at the fracture with potential disturbance of fragment blood supply. In the presense of comminution zones the classical principle of plate osteosynthesis with absolute stability has to be changed to a bridging plate osteosynthesis.

Due to a high complication rates with infection, refracture delayed healing, non-union and soft-tissue problems, the concept of biological bridge plating (16) was developed with a minimal-invasive fixation technique.

The main concept is based on fracture incisions awax from the original fracture site without disurbance of the fracture haematoma allowing secondary bone healing.

By this more biological approach significant advantages with respect to healing, infection, refracture and bone grafting were achieved in comparison to conventional plating.

Therefore, indications for plate osteosynthesis at the femoral shaft can be (18):

- a narrow medullary canal (Fig. 6)
- a sclerotic, locked medullary canal
- significant axis deviation of the femur
- medullary canal contamination
- pediatric femoral shaft fractures
- hypertrophic femoral non-union after intramedullary nailing
- significant soft-tissue injury/compartment syndrome (Fig. 7)

A retrospective analysis of 14 high-energy trauma multifragmentary femur fractures treated biological plate fixation. Of 8 patients with a more invasive approach 7 had fracture healing after 4 months and one developed non-union. 6 patients with proximal and distal incisions showed the same fracture healing time (29).

In a review of 697 femoral fractures treated by biological plating an overall union rate of 98.4% was seen.

Malunion occurred in 0–29% and reoperation was necessary in 0–23%. A the infection rate was low (2%) biologic plate fixation was believed to be a viable alternative to modern nailing techniques (37).

In a retrospective analysis a low complication rate was seen with 2.5% nonunions and 5% infections in 40 patients with either open or submuscular plating of the femoral shaft (54).

In a recent prosepctive analysis 57 less invasive percutaneous plate osteosynthesis (MIPPO) of femoral shaft fractures was performed in simple fracture types (AO type A). Adequate healing occurred in 95% of patients. Complications were acceptable with 3.5% implant failure, 10.5% valgus deformities and 8.8% external malrotational alignment and one superficial and one deep wound infection (2).

A comparable analysis of IMN and biological internal plating showed no difference regarding union time, complication rate and functional results (30).

Overall, results after biological plating of femoral shaft fractures is a good alternative to IMN for simple femoral shaft fractures, in patients with multiple trauma and when anatomical contraindications are present not allowing IMN.

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