Management of Femoral Shaft Fractures

Léčení zlomenin diafýzy femuru

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SUMMARY

Femoral shaft fractures are severe injuries and are often associated with a high impact trauma mechanism, frequently seen in multiple injured patients. In contrast an indirect trauma mechanism can lead to a complex femoral shaft fracture especially in elderly patients with minor bone stock quality. Hence management of femoral shaft fractures is often directed by co-morbidities, additional injuries and the medical condition of the patient. Timing of fracture stabilization is depended on the overall medical condition of the patient, but definite fracture fixation can often be implemented in the early total care concept in management of multiple injured patients.

The treatment of choice is intramedullary fracture fixation. Further development of existing intramedullary nailing systems now offer comfortable handling and different locking options. Ipsilateral fractures of the neck and shaft are therefore facilitated in management. Then again increasing numbers of obese patient are representing a new patient group with challenging co-factors in fracture management.

Sufficient preoperative planning is helpful to choose the most adequate fixation device. Correct reduction of the fracture and perioperative control of the axis and rotation is mandatory to avoid postoperative malrotation, which still represents the most frequent complication.

INTRODUCTION

Femoral shaft fractures occur in 10–37 / 100.000 patients per year (1, 37), and mainly male young patients are affected (median age 27 years) compared to the fracture of the elderly in female patients (median age 80 years). In multiple injured patients femoral fractures account for up to 30%, with open femoral fractures found in 11,5 in 100,000 injured persons (2).

Genesis / Epidemiology

Main trauma mechanism for femoral shaft fractures is a direct fall on the affected limb (37). A direct impact trauma mechanism or high-energy trauma leads to simple shaft fractures with related extensive soft tissue damage. Rotational or wedge type shaft fractures are due to an indirect trauma mechanism with minor soft tissue damage. Large segmental bone defects or comminuted shaft fractures are seen after gunshots or explosive trauma exposure with significant soft tissue damage.

Another genesis of femur fractures is carcinogenic. Osteolytic or osteoblastic metastasis can lead to pain and immobilisation due to a pathologic femur fracture. Surgical therapy is focused on immediate fracture stabilisation offering a durable and solid fixation. Parallel increasing numbers of fatigue femur fractures are observed following a long-term therapy with bisphosphonates in osteoporotic patients leading to atypical femur fractures, prevalently in the subtrochanteric region. Limited reports estimate biphosphonate related atypical subtrochanteric fractures with one per 1000 fractures per year (26). Postulated pathophysiology for these atypical fractures is an increase of advanced glycated end-products, increased mineralisation and the accumulation of microfractures in the region of maximal tensile loading (34).

Overall blood loss in closed fractures is 0.5–1.5 litres, and development of a compartment syndrome is found in 1% of all trauma cases. 2–5% of open femoral shaft fractures are seen in multiple injured patients (37).

Anatomy

The femoral bone is the largest and strongest in the human body. Its anatomical shape includes a physiologic antecurvation and its femoral neck an anatomical antetorsion of 125˚–130˚. Three main muscular groups surround the femoral bone, the quadriceps muscle ventrally, the hamstring or ischiocrural muscles (long and short head of the biceps muscle, semitendinosus and semimembranosus muscle) dorsally and the adductor group on the medial side.

Fracture displacement often follows a predictable pattern caused by the pull of muscles attached to each fragment.

- in proximal shaft fractures the proximal fragment is flexed, abducted and externally rotated because of gluteus medius and iliopsoas pull; the distal fragment is frequently adducted
- in mid-shaft fractures the proximal fragment is again flexed and externally rotated but abduction is less often seen, frequently these fracture types resemble a shortened extremity
- in lower third fractures the proximal fragment is adducted and the distal fragment is tilted by gastrocnemius pull.

Blood supply to the femoral bone is guaranteed by the femoral artery, which branches into the deep femoral and the superficial femoral artery. Especially in fractures at the junction of the middle and distal thirds of the femoral shaft careful attention has to be placed as the femoral artery in the adductor canal can be damaged.

Clinical assessment

Besides swelling, instability and deformity of the leg, the affected limb will present shortened and with malrotation. The patient is unable to lift the leg or flex the knee joint. Clinical evaluation includes inspection and documentation of the soft tissue condition and the neurovascular condition. If no peripheral pulse is palpable ultrasound investigation is mandatory. In 40% of all cases ligamentous and menisceal collateral injuries of the knee are documented (4). Additional, and often overseen, femoral neck fractures are found in 2.5–6% of all femoral shaft fractures. In high velocity injuries ipsilateral hip dislocation and acetabular fractures have to be excluded. The combination of ipsilateral femoral shaft and tibial shaft fractures, producing a 'floating knee', signals a high risk of multi-system injury in the patient. The effects of blood loss and other injuries, some of which can be life-threatening, may dominate the clinical picture.

Radiological assessment

Conventional radiographs of the femur in two planes are sufficient in a mono-injured patient. CT scans should be performed in multiple injured patients for exclusion of ipsilateral hip or acetabular fractures and for further surgical planning in complex fracture patterns. If a vascular injury is suspicious angiographic evaluation has to be performed.

A plain chest x-ray is useful as there is a risk of adult respiratory distress syndrome (ARDS) in those with multiple injuries.

CLASSIFICATION

Classification systems should guide the surgeon in his treatment options and predict outcome. Femoral shaft fractures are generally classified to the alphanumeric coding system of the AO (28), (see Fig. 1).

A type: simple fracture, with 2 fragments
A1: spirale,
A2: oblique,
A3: transverse.

B type: more than 2 fracture fragments, but the main parts are still in contact
B1: spirale,
B2: oblique,
B3: transverse.

C type: complex fracture type, the fracture fragments are not in contact to each other
C1: 1 or 2 spirale wedges,
C2: oblique or transverse, multi étagère,
C3: complex, comminuted, with segmental bone defect.

Further sub-classifications, which are more specific are known. Especially for the subtrochanteric region numerous ones have been introduced over the years to classify femur fractures of that part. But the lack of reproducibility concludes inaccuracy and reliability in use, as they are mainly descriptive with little bearing on management and outcome (see Table 1).

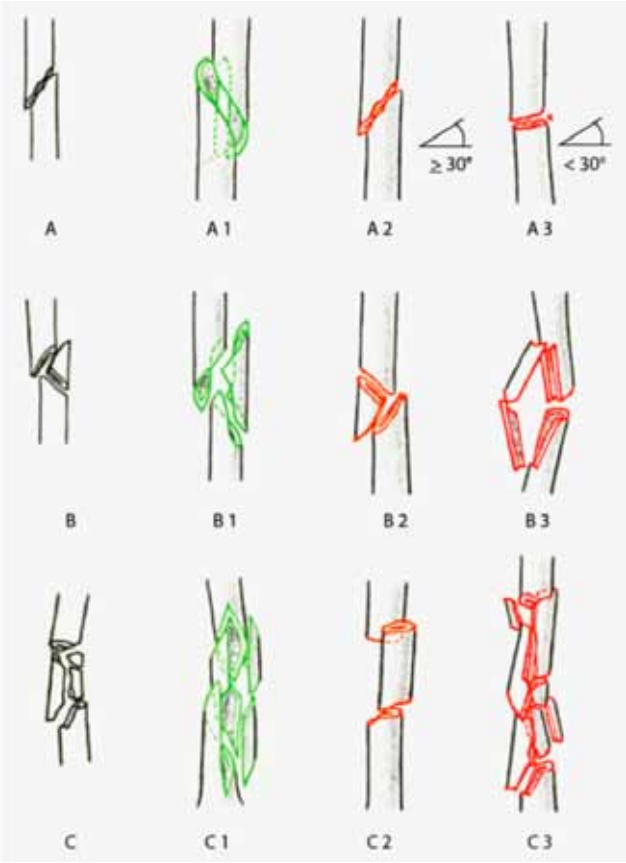


Fig. 1. Graphic demonstration of the AO definition of femoral shaft fractures (17).

Table 1. Overview of known classification systems for subtrochanteric femur fractures (3)

Study	Proximal Border	Distal Border	Number of Subdivisions
Boyd & Griffin (1949)	NS	NS	2
Watson et al (1964)	DBLT	10 cm	>10
Fielding (1966)	PBLT	5 cm	4
Cech and Sosa (1974)	NS	NS	4
Zickel (1976)	PBLT	10 cm	6
Seinsheimer (1978)	DBLT	5 cm	7
Pankovich et al (1979)	DBLT	5 cm	4
Waddell (1979)	NS	NS	3
Harris (1980)	DBLT	5 cm	6
Malkawi (1982)	NS	NS	5
Russell & Taylor (1987)	NS	NS	3
AO Müller (1990)	DBLT	3 cm	9
Wiss & Brien (1992)	DBLT	7.5 cm	3
Parker & Pryor (1994)	DBLT	5 cm	

NS = Not stated; PBLT = Proximal border of lesser trochanetr; DBLT = Distal border of lesser trochanetr

Distal femur fractures are due to a high-energy trauma and most frequently found in young patients. A significant displacement of the fracture fragments is seen. Supracondylar fractures show no intra-articular fracture extension, whereby intercondylar fractures have intra-articular extension. Classification follows the alpha numeric coding system of the AO / OTA.

Type A: extra-articular
Type B: unicondylar
Type C: bicondylar

Periprosthetic fractures of the distal femur shaft are increasing. They can occur intraoperatively or during the course of the postoperative period. Treatment of these fractures is challenging and frequently associated with co-related orthopaedic and systemic complications. For description and planning of surgical management the Vancouver classification is most widely used (6).

Type A: fracture of the trochanteric region (A–Greater trochanter, B–lesser trochanter).
Type B: fracture around or just distal to the stem (B1–stable and well fixed prosthesis, B2–unstable / loose prosthesis, B3–loose implant, inadequate bone stock).
Type C: fracture well distal to the stem.

Further classification systems have been developed for a more detailed description of periprosthetic fractures of the distal femur region respecting as well the stability of the prosthesis and bone stock quality (22, 27).

Recently the UCS (Unified Classification System) for classification of periprosthetic fractures has been introduced, which core principles include location of the fracture in relation to the implant, fixation of the implant, and the quality of the implant surrounding bone stock (5). This new classification system is based on the AO principle and is applicable for all bones and joints. It follows an alphanumeric code. Bones are marked with arabic numbers, following the AO / OTA Fracture and Classification system (1–34), joints are identified with roman numbers (I–VI), proceeding from the shoulder (I) to the ankle (VI) joint. The alphabetic code further describes the location of the fracture in relation to the implant:

Type A: Apophyseal
Type B: Bed of the implant (B1: good bone, no implant loosening, B2: good bone with implant loosening, B3: poor bone or bone defect with implant loosening)
Type C: Clear of the implant
Type D: Dividing the bone between two implants
Type E: Each of two bones supporting one arthroplasty
Type F: Facing and articulating with a hemiarthroplasty

For example, a periprosthetic fracture of the distal femur with implant loosening would be classified as V.3 B2.

Femoral fractures in children are classified following the alphanumeric system of the AO-PAEG (32). Subtrochanteric fractures are described as 31-M/3.1-III, shaft fractures as 32-D/4 or 5. 70% of these juvenile fractures occur in the midshaft region, 22% are located proximally and 8% in the distal diaphysis (9).

Fig. 2. Multiple injured 25-year-old man, who sustained a blunt thoracic injury, a pelvic fracture, a multifragmentary fracture of the lower leg with a compartment syndrome and a simple femoral shaft fracture after a motorbike accident. Initial treatment following the Damaged Control Orthopaedics (DCO) concept with placement of external fixators (a). Delayed definite stabilization with an antegrade nailing (AFN) with dynamic locking distally (b, c, d).

For completion of sufficient description and classification of open femur fractures the soft tissue classification in open fractures is repeated:

Gustilo and Anderson, originally designed to classify soft tissue injuries in tibial shaft fractures (10).

– Grade I: clean skin opening of less than 1 cm, usually from inside to outside, minimal muscle contusi-

on; simple transverse or short oblique fractures.
– Grade II: laceration more than 1cm long, with extensive soft tissue damage; minimal to moderate crushing component; simple transverse or short oblique fractures with minimal comminution.
– Grade III: Extensive soft tissue damage, including muscles, skin, and neurovascular structures; often a high energy injury with a severe crushing component.
– Grade III A: extensive soft tissue laceration, adequate bone coverage; segmental fractures, gunshot injuries; minimal periosteal stripping.
– Grade III B: Extensive soft tissue injury with periosteal stripping and bone exposure requiring soft tissue flap closure; usually associated with massive contamination.
– Grade III C: Vascular injury requiring repair.

Fig. 3. 61-year-old woman with a pathological femoral shaft fracture (metastasis of a breast cancer) who received surgical treatment in another facility, initially with a plate ostesynthesis, followed by compound synthesis due to implant failure. Transfer to our tertiary unit with a broken plate. Decision was made to change the concept towards reamed antegrade nailing.

a|b|c

Tscherne and Oestern classification (36)

Respects size of wound, level of contamination, and mechanism of fracture
– Grade I: small puncture wound without associated contusion, negligible bacterial contamination, low-energy mechanism of fracture.
– Grade II: small laceration, skin and soft tissue contusions, moderate bacterial contamination, variable mechanisms of injury.
– Grade III: large laceration with heavy bacterial contamination, extensive soft tissue damage, frequent associated arterial or neural injury.
– Grade IV: incomplete or complete amputation with variable prognosis based on location of and nature of injury (e.g. cleanly amputate middle phalanx vs. crushed leg at proximal femoral level).

TREATMENT / MANAGEMENT

The fracture pattern will give a guide for the emergency care and treatment. For immediate control of pain, bleeding and shock management fracture reduction maintains blood volume, and a definite plan of action can be instituted as soon as the patient's condition has been fully assessed.

As femoral fractures are frequently seen in multiple injured patients discussions of a stepwise treatment scheme have already raised in the 1970ies. In this decade several studies highlighted the effectiveness of early definite treatment or Early Total Care (ETC) of femoral shaft fractures as this deduced pulmonary complications, mortality and hospital Length of Stay (LoS). But this statement was later questioned in chest or head injured patients following the two–hit hypothesis (21). First a traumatic event is followed by a second event (early surgery and blood loss induces inflammatory changes that may increase both morbidity and mortality), which leads to an overwhelming inflammatory response accumulating in acute respiratory distress syndrome (ARDS) or multi organ failure (MOF) (21, 30). Scalea et al. (30) later proposed the Damage Control Orthopaedics (DCO) strategy with achieving early skeletal stability by placement of external fixators and a delayed definite surgical treatment. This management reduces the second hit by minimizing blood loss and anaesthesia time. Further discussions enrolled the often difficult definition of declaring multiple injured patients as medical stable or instable. Therefore the term Borderline patient was implemented (21), in which an increased pulmonary risk for extensive surgical treatment in the early posttraumatic time frame is stated. Several literature reviews and multi-disciplinary studies have been presented comparing outcome between ETC and DOC, but still no evidence is found (25). A potential benefit is found for early definite treatment of multiple injured patients on the incidence of ARDS and LoS (7). No benefit was shown for early treatment on mortality (18).

Subtrochanteric femur fractures are generally treated after the surgeon's personal preference, but fixation devices can be divided into intramedullary or extra-

Fig. 4. 58-year-old woman with a pathologic femoral shaft fracture due to metastasis of a lung cancer (a, b, c, d). Initial fracture fixation with an antegrade femoral nail and distal locking with angular stable screws (ASLS®, DePuy-Synthes) (e, f). 3 months later the patient represented again with a painful leg and radiographic documentation of the broken IM Nail (at the most proximal one of the distal locking screws g, h). For re-fixation of the fracture a plate osteosynthesis was chosen (i, j, k).

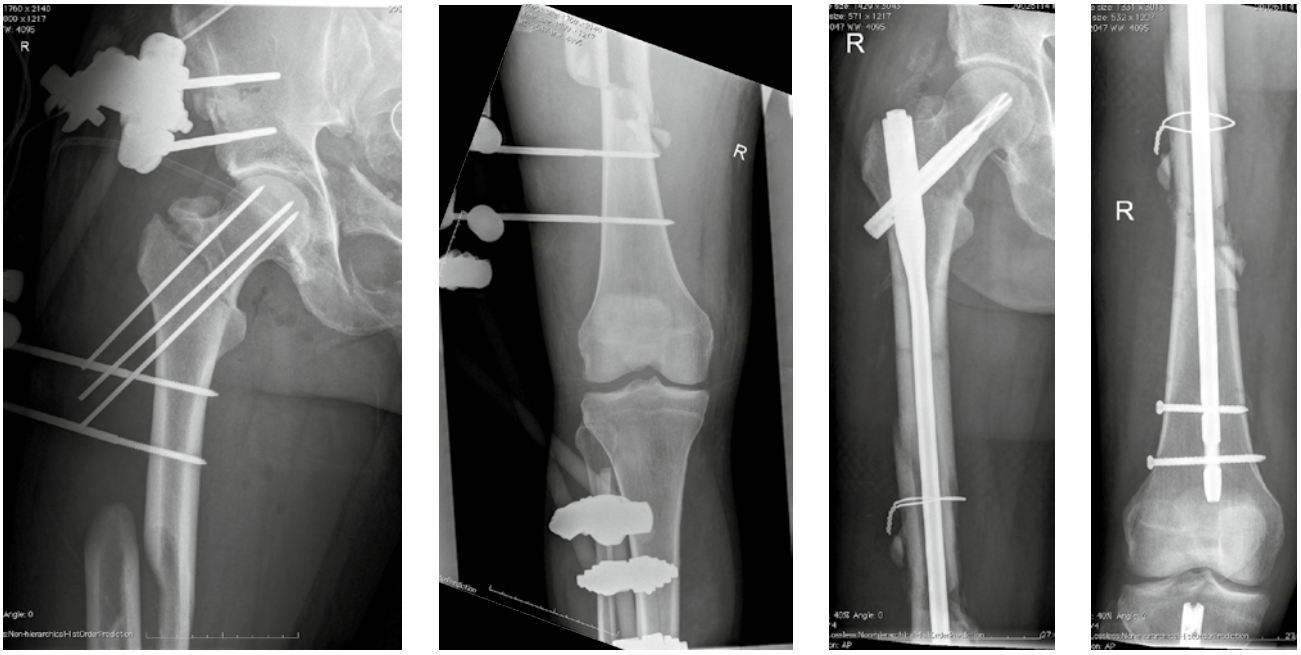


Fig. 5. A 35-year-old polytraumatized man sustained an ipsilateral pertrochanteric and femoral shaft fracture after a car crash. After initial stabilization with an external fixator definite stabilization was performed with a long proximal femoral nail (PFN-A) and cerclage wiring.

a|b|c|d
e|f

medullary implants. Numerous studies comparing outcome between extramedullary (plates, gliding screws) and intramedullary (Interlocking nails) devices show different results regarding non-union or implant failure. The dynamic hip screw (DHS) has been reported to be the most effective of the extramedullary implants and could be used for subtrochanteric fractures if the fracture extends into the trochanteric region (3).

In general four different techniques for intramedullary nailing for the fixation of open fractures in long bones are known (12):

1. unreamed, unlocked: e.g. Ender nail, low infection rate, mechanically insufficient,
2. reamed, unlocked nailing: relies on overreaming to provide stability through bone-nail surface contact, high infection rate,
3. reamed locked nailing: limited reaming, stability due to interlocking screws,
4. unreamed nailing: relies on interlocking screws, better outcome, but higher incidence of screw breakage.

The intramedullary nail fixation still represents the gold standard in the management of femoral fractures (Fig. 2). Despite the location of the fracture site, intramedullary nailing offers sufficient stability with early functionality in a short and minimally invasive surgical procedure (Fig. 3). The principle of this fixation technique goes back on to the Kuentscher wires (13) with intramedullary bridging of the fracture site. In per- and subtrochanteric femoral fractures devices with a gliding mechanism and additional stabilization of the collum–diaphysis angle is used. A combination of these features is represented in the design proximal femur nails (e.g. PFN-A) and antegrade or lateral femoral nails (e.g. AFN, LFN, DePuy Synthes®, Oberdorf, Switzerland). Usually an antegrade placement of the intramedullary nails is most widely performed (Fig. 4). The retrograde nailing technique finds more popularity nowadays and is probably indicated in obese patients (easier entry point), ipsilateral femoral neck fractures, ipsilateral tibial shaft fractures (one approach), instable vertebral, hip or acetabular fractures (no crossing of approaches) and in pregnant patients (less radiographic dose). Since today no evidence has proven better outcome for retrograde versus antegrade nailing position (35). No essential differences between antegrade and retrograde technique could be detected regarding pain, complication rate,

Fig. 6. 58-year-old woman after a car accident with a distal femoral shaft fracture and a multifragmentary lower leg fracture. An additional "Hoffa fracture" of the medial condyle was seen. Based on this fracture pattern we decided against nailing and for plate osteosynthesis (distal femoral LISS).

a|b|c|d
e|f

healing time and duration of bed confinement and surgery (19, 23). But retrograde nailing should be discussed for fracture fixation in distal femoral shaft fractures.

Whereas in tibial shaft fractures reamed placement for intramedullary nailing devices is favoured and less complications for embolism due to the smaller tibial bone marrow cavity and less extensive venous drainage system, unreamed placement of intramedullary nails are recommended for management of femoral shaft fractures (38). The underlying pathophysiology during reaming is the increase of pressure intramedullary, which presses bone marrow content and blood into the circulation during repetitive reaming steps. This becomes relevant if co-factors are present, e.g. volume deficit, shock, lung contusion and / or pre-existing pulmonary impairment. Blood or fat embolism is the consequence with consecutive impairment for the lung or brain. Experimental and echocardiographic investigations show, that the velocity of the nail insertion and the gap between the nail and cortical bone at the entrance in the distal fragment determine the amount of embolized material (38). Therefore unreamed nailing is the treatment of choice in femoral shaft fractures. If an ipsilateral fracture of the femoral neck is present fracture management is facilitated since the introduction of the long PFN or the AFN (DePuy Synthes®), (Fig. 5). These two implants offer suitable placement of recon and locking screws to support these fracture entities (31).

Plate fixation of femoral shaft fractures is the procedure of choice if an intramedullary fixation is technically not manageable (e.g. hip or knee implants in situ, or previous surgical fixation such as corrective osteotomy), in type III open fractures, additional open fractures in the surgical field (e.g. simultaneous open hip fracture) or presence of a compartment syndrome. Different plating devices have been introduced based on the principle of the limited contact dynamic compression (LCDC) plate such as the less invasive stabilization system (LISS) plate (DePuy Synthes®) or non-contact bridging (NCB) plate (Zimmer®, Warsaw, USA). In critical cases of proximal femur fractures the use of a reversed locking plate proved good to excellent results (16). In distal femoral fractures the LISS plate competes against retrograde nailing devices (15), (Fig. 6). Biological bridge plating with minimal invasive fixation technique is a reasonable alternative to intramedullary nailing for simple femoral shaft fractures in selected patients (8) (Fig. 7). Management of open

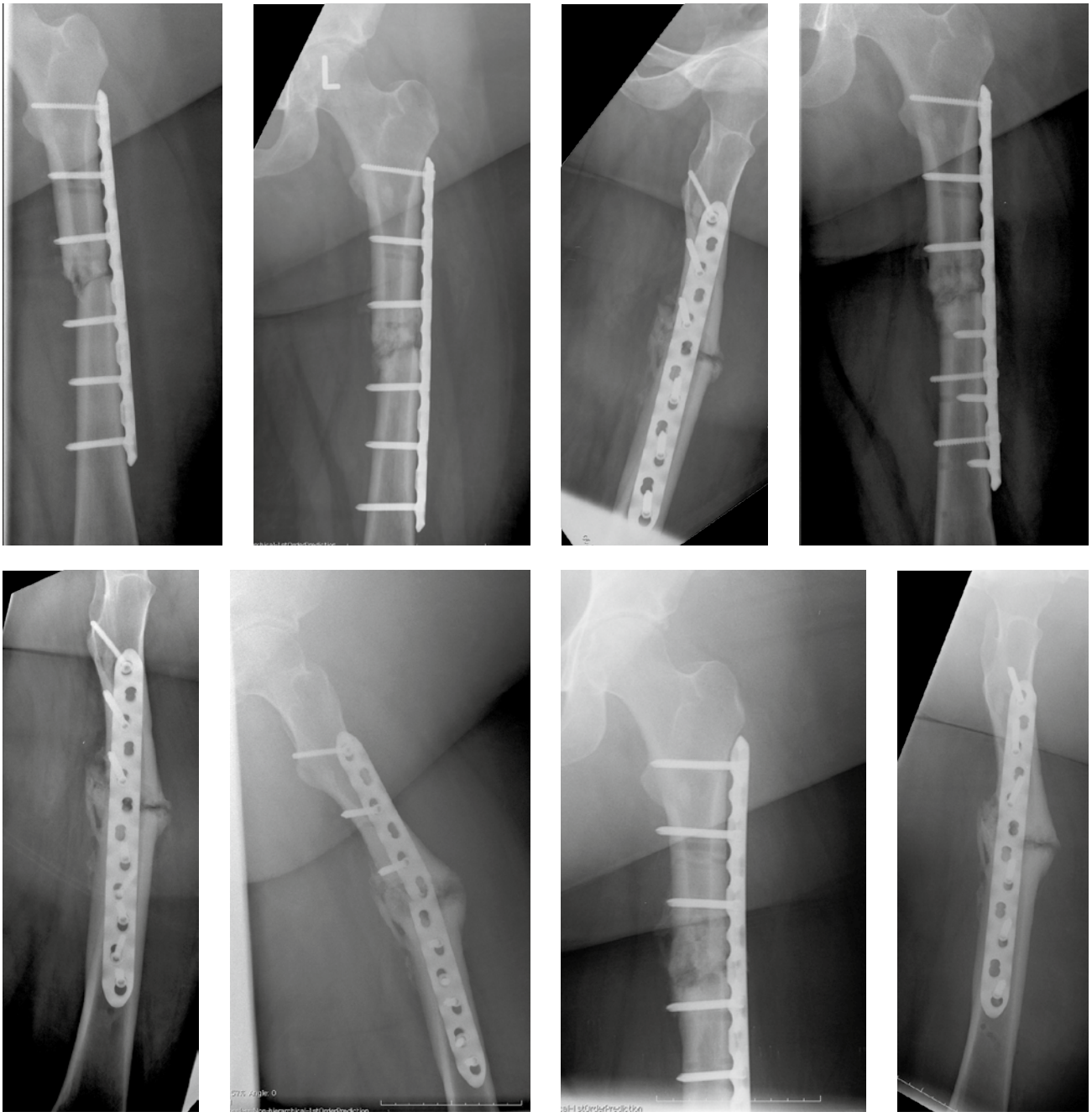
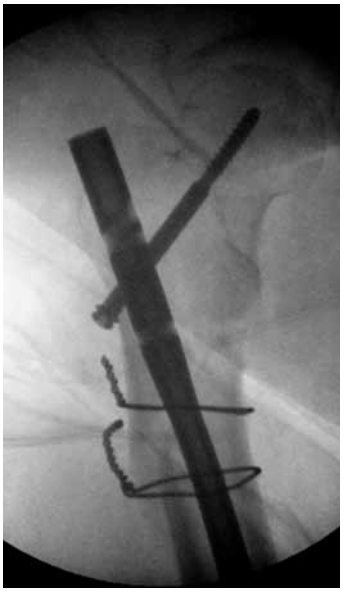


Fig. 7. A 32-year-old obese polytraumatized woman presented with this femoral shaft fracture. Due to problems with the approach/entry point for the nail we decided to stabilize with plate osteosynthesis. After 4 months a pseudarthrosis was documented and a re-osteosynthesis was performed. After 13 months the 4.5mm LCP broke and again a 4.5mm LCP was chosen for fracture re-fixation. Osseous consolidation after 4 years.

a|b|c|d
e|f|g|h
i

Fig. 8. A subtrochanteric fracture (a) in a very obese (BMI 61) 64-year-old woman (b). Immediate fracture fixation with an AFN on fracture table (c, d, e). On day 1 after surgery the cut out of the proximal head screw was seen without mobilisation of the patient (f) happened and implant removal with change of the implant to a PNF-A was performed (g, h).

a b
c d
e f g h



fractures follows the strategy of initial fracture stabilization by placement of an external fixator, wound debridement and delayed definite fracture treatment.

With increasing numbers of obese patients the challenge of management of femoral fractures is predominantly the surrounding soft and fat tissue. In defined cases placement of the devices and gadgets of the instruments is difficult as the space between skin and bone is compromised (Fig. 8). Adequate intraoperative positioning and obtaining accurate reduction and stable fixation may require special considerations and preparation (33). Hence correlated complications like wound infection or skin ulcera due to patient's positioning are increased. Often extensive approaches are the remaining solution for proper definition of insertion points or plate placement.

COMPLICATIONS

After surgical management of femoral fractures early and late complications may occur. Early complications are

- shock, as up to 2 litres of blood can be lost even in a closed fracture
- nerve compression (pudendal nerve 5–9 %, sciatic nerve 1–2%) after surgical positioning
- compartment syndrome 1–2 %
- infection 3–4%, prophylactic antibiotics and careful attention to the principles of fracture surgery should be obtained
- deep venous thromboembolism 1–10% due to prolonged bed rest, prophylactic anticoagulants should be given
- arterial lung embolism in isolated femur fractures 2–4%, in multiple injured patients 8–11%, which may result in ARDS as small fat emboli being swept to the lungs

Late complications are most commonly malrotation in up to 22%, with more than 15% of rotational malalignement in comminuted fractures (AO type C) and surgical fracture fixation during night shifts (11). Surgical correction is achieved after CT scan evaluation by re-placement of the intramedullary nail.

Declaration of a delayed fracture union or non-union can vary with the type of injury and the method of treatment. It is seen in 1–5% after intramedullary fracture fixation and in 10–15% after plate fixation. A review of literature to formulate evidence based guidelines for the treatment of femoral shaft fracture nonunions, evidence for plating is stated if a nail is the first treatment. After failed plate fixation, nailing has a 96% union rate. After failed nailing, augmentative plating results in a 96% union rate compared to 73% after exchanging intramedullary fixation devices (29).

Knee joint stiffness is due to soft-tissue adhesions during treatment or the knee joint may be injured at the same time. Hence early physiotherapy and repeated evaluation of the range of motion is mandatory. Critical voices of retrograde nailing being a high risk for intraarticular knee infection could be corrected. In a retrospective multi-centre study low risk for knee infection in retrograde nailing of open femoral fractures was shown (1.1%) (20). Heterotopic ossifications are found in up to 25% at the nail insertion point (14). Prophylactic, intermittent therapy with non-steroidal anti-inflammatory drugs like Indomethacin may prevent these osseous formations.

TIPS & TRICKS

To restore leg length, correct axis and rotation correct reduction of the fracture is mandatory. After positioning of the patient on a traction table closed reduction of the femoral fracture is gained by extension, ab- and adduction and external or internal rotation of the leg. But especially in young and muscular patients and fracture lines in the subtrochanteric region sufficient closed reduction can be difficult. Monocortical placement of a Schanz' screw or threaded K-wire can be helpful for external manipulation of the distal fragment in a 'joystick technique'. Use of the F-tool for further support in closed reduction is equally recommendable. Mini-open reduction with palpable control of the realigned fracture parts might be necessary in comminuted fractures.

CONCLUSIONS

Femoral shaft fractures have a high incidence in multiple injured patients. Management of the fracture under these circumstances depends on the overall medical condition of the patient. No evidence has been proven yet for a definite treatment scheme but a trend is found for early definite care for patients in clinically stable conditions. This is mainly due to the further development of modern intramedullary nailing devices which handling and insertion are facilitated by design and fixation options. Median surgical time and blood loss could have been reduced and hence risk of thromboembolism is minimized. Individual cases can be challenging in management, especially periprosthetic femoral fractures, and plate fixation might be the more suitable fixation method. Beside general postoperative complications malrotation still is the most frequent one. Perioperative radiographic control of the projection of the lesser trochanter, the width of the cortex in the aligning fragments or the cross-section dimension of the intramedullary space are not reliable parameters for intraoperative control of the rotation. Postoperative CT-scan assessment evaluates definite leg axis and rotation.

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