Foundations of Intramedullary Femoral Shaft Fracture Fixation: Avoidance, Recognition, and Management of Common Pitfalls

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ABSTRACT

Intramedullary nailing is an effective treatment of femoral shaft fractures. However, this procedure has several common complications and technical problems that can interfere with full recovery in some patients. The purpose of this review article is to expand on the literature with the authors' own experiences to summarize the following common complications of femoral nailing: missed injuries, suboptimal surgical timing, malreduction, reaming errors, implant insertion errors, pain-management problems, and implant removal errors. Strategies are also identified to help avoid and manage these complications.

Keywords: Femur; Fracture; Trauma; Intramedullary nail; Fixation; Complications; Surgical technique; Implant

INTRODUCTION

Nailing of femoral shaft fractures is a common intervention that generally provides excellent functional outcomes and healing rates.[1-3] This is often perceived as a technically easy procedure that yields positive results with low risk of complication.[4-6] However, complications and technical problems have been reported, but tend to be underappreciated.

This review identifies common complications, technical problems, and solutions associated with nailing of femoral shaft fractures in adults. By combining the data from various studies, and the authors' own experiences, this study aims to provide orthopaedic surgeons with increased awareness of these problems and considerations for avoidance and treatment. These problems include: missed associated injuries, suboptimal surgical timing, malreduction, reaming errors, implant insertion errors, pain management, and implant removal errors.

MISSED ASSOCIATED INJURIES

Femoral shaft fractures can occur as isolated injuries (80.0%) or in combination with other injuries (20.0%).[1] They are almost always immediately diagnosed, owing to gross deformity and pain, but associated injuries are often overlooked initially.[7,8] Numerous authors have reported on major and minor associated injuries and their tendency to be missed for various reasons (Table 1).[7–15]

The most common and serious missed injuries are femoral neck fractures, reported in about 5.0% of all cases.[16-18] The second most common associated injury is knee ligamentous damage. Non-limb threatening injuries include scaphoid and foot fractures; however, these

Table 1. *Why Associated Injuries of Femoral Shaft Fractures are Commonly Missed*

Number	Initial Conclusion Action	Result
1	Satisfied with search	Injury was apparent on existing imaging in retrospect, but not recognized initially.
2	Failure to recognize subtlety	Injury was probably present on initial imaging, but not recognized.
3	Failure to image	Optimal imaging was not obtained.
4	Radiographically occult	Even in retrospect, the injury was not apparent on initial imaging.
5	Injury was not present initially	Occurred as an iatrogenic result of subsequent treatment.

can result in severe debilitation to patients long after routine healing of femoral shaft fractures.[12,13]

Missed injuries can be avoided by having a high index of suspicion, obtaining serial radiographs, and performing multiple serial physical examinations following initial injury. When other injuries are detected, they should be treated appropriately to avoid potentially serious sequelae.

Femoral Neck Fractures: Priority Treatment

Potential catastrophic complications are associated with even minimally displaced femoral neck fractures, which makes treatment a priority. In particular, avascular necrosis (AVN) and nonunion can have especially devastating effects in younger patients for whom arthroplasty is not an ideal salvage procedure. Femoral neck fractures can occur due to the patient's initial trauma, but also as a consequence of femoral nailing.[19] When a femoral neck fracture is identified, priority should be placed on addressing the femoral neck prior to the shaft fracture (Table 2). Initial recognition of associated femoral neck fractures is facilitated by a high index of suspicion. The surgeon should rule out an associated femoral neck fracture by evaluating multiple images. In addition to radiographs at the fracture site, initial radiographic evaluation should include dedicated proximal femur anteroposterior (AP), lateral, and internal-rotation radiographs. A preoperative fine-cut computed tomography (CT) scan of the hip can be also considered, but is not 100.0% sensitive to visualize femoral neck fractures.[20] The authors recommend including a clinical note such as "femoral shaft fracture without evidence of femoral neck fracture to date." Intraoperative fluoroscopy should also be performed before and after the nail insertion. Lastly, postoperative radiographs of the femoral neck should be obtained along with repeat radiographs after the patient starts weight bearing.

When an ipsilateral neck fracture is diagnosed, anatomic reduction of the fracture should be performed with stable fixation. There are multiple fixation options available to the treating surgeon, without absolute consensus in the literature to date as to which approach is best. The first option is to use a single construct, such as a cephalomedullary nail to fix both fractures. The second is to address the femoral neck fracture with implant fixation (sliding hip screw, cannulated screws, etc.) followed by retrograde fixation of the femoral shaft fracture with a second implant. The single construct option has been found to lead to malreduction at a higher rate than the multi-construct option.[21] There is also a two-construct approach involving an antegrade intramedullary device in which cannulated screws are placed into the femoral neck adjacent to the existing implant. However, this "miss-a-nail" technique can lead to suboptimal positioning of cannulated screws due to the pre-existing implant, and is most often employed when an ipsilateral femoral neck is discovered intra-operatively while nailing a presumed isolated femur shaft fracture.[22]

Table 2. *Management Recommendation to Recognize Associated Femoral Neck Fractures*

Preoperative	Review radiographic findings for possible neck fracture. AP and lateral dedicated hip plain radiographs traction consider CT.
Intraoperative	Fluoroscopic AP and lateral images Fluoroscopic AP and lateral images after insertion Rotational fluoroscopy after nailing
Postoperative	Dedicated plain radiographs (AP and lateral) of the hip immediately after the procedure Follow-up AP and lateral when patient is ambulating Clinical examination for hip pain with rotation and weight bearing postoperatively

Knee Ligamentous Injury

Initial and postoperative evaluation should include examination of the knee ligaments. A multi-center analysis found that 20.0% of femur shaft fractures had an associated knee ligamentous injury, 30.0% of which initially went undetected prior to internal fixation of the fracture.[23] These ligamentous injuries included both cruciates and collaterals, and 36.0% of ligamentous injuries involved more than one major ligament.

Because the preoperative examination can be unreliable in patients with femoral shaft fractures, another examination should be performed at the completion of femoral nailing and dictated as part of the operative note.[9] To this point, after the patient is awake and stabilized, another physician should perform and document a secondary examination of all body parts to identify any other missed injuries. All extremities should be palpated, and tender areas should be imaged on plain radiographs.

SUBOPTIMAL SURGICAL TIMING

The optimal timing of nailing is 2 hours to 48 hours after initial injury. Problems are more likely to occur when patients undergo treatment too early or delayed beyond 72 hours. Timely stabilization of the fracture allows for early ambulation and avoidance of complications related to immobility, such as infections and skin issues. Reaming of femoral shaft fractures allows for insertion of a nail, but pushes fatty marrow contents into the circulation, and ultimately leads to fatty deposition in pulmonary cells.[24-25] Historically, the guiding thought in orthopaedic surgery was that early-reamed intramedullary nails could contribute to pulmonary depression and the development of acute respiratory distress syndrome (ARDS) in the multiply injured patient, particularly with chest trauma. This led to the employment of the “Damage Control Orthopaedics” approach, which includes the application of an external fixator while the patient is in extremis and requires further resuscitation or procedures, with later return to the operating room (OR) for definitive femoral nailing. However, there is now a body of literature suggesting that reaming for intramedullary implants is a safe procedure that does not contribute to an increase in pulmonary complications or mortality in the traumatized patient.[26] There are still cases where “Damage Control Orthopaedics” should be employed. For example, if there is a clinical need to limit anesthesia time, temporary stabilization with external fixation significantly minimizes operative time as compared to placement of an intramedullary implant. Morshed et al. [27] showed a 50.0% decrease in mortality in delayed definitive management, especially in patients with serious traumatic abdominal injuries. Other forms of damage control include using unreamed nails, small diameter nails, and delayed placement of locking screws to manage initial operating time and surgical stress to patients with multisystem trauma. Femoral nailing delayed more than 72 hours is associated with increased difficulty obtaining adequate reductions due to powerful thigh muscle spasms that shorten femoral fractures as surgery is delayed. This process is even more relevant in the setting of polytrauma, as patients with head injuries form bony calluses at an accelerated rate and have increased muscle tone.[28] When delayed, intraoperative reduction of a femoral shaft fracture is difficult, and more traction is needed to get the fracture out to proper length. This increases the risk of damage to the sciatic, femoral, and peroneal nerves.[29] In this difficult clinical scenario, other strategies have been employed for obtaining reduction, such as application of spatial frames.[30]

MALREDUCTION

Malreduction is a common error associated with femoral nailing. Diligence with radiographic assessment and physical examination is especially important in recognizing rotational and length malalignment. Inaccurate entry points will result in secondary malreduction.

Treatment of femoral shaft fractures should restore length, alignment, and rotation. The anatomic reduction of all fragments is not needed to obtain excellent outcomes. Abundant callus formation compensates for structural weakness caused by displaced fragments. In most fractures, the intramedullary nail will automatically align the proximal and distal medullary canals, resulting in reduction of angulation and displacement in the sagittal and coronal planes. However, length and rotation are not automatically restored and require specific techniques by the surgeon to reduce. Some fracture patterns (e.g. metaphyseal comminution) do not spontaneously reduce when the

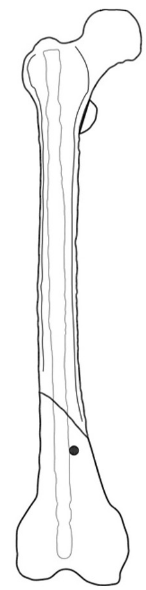

Figure 1. *Demonstration of blocking screw placed in the distal femoral fragment, allowing for optimal position of the femoral nail and correction of coronal alignment.*

nail is placed, due to the increased distance between the outer surface of the nail and the endosteum of the femur in the coronal and sagittal planes. These fracture patterns require special techniques, such as blocking screws to achieve acceptable sagittal and coronal alignment (Figure 1).

Alignment and Length

Comminuted fractures in the proximal or distal third of the femoral shaft are particularly susceptible to malunion. In this instance, blocking screws help obtain acceptable alignment. For example, in a distal fracture with apex lateral angulation, a blocking screw can be placed from anterior to posterior medial in the medullary canal in the distal segment of the fracture (Figure 1). The intramedullary canal is effectively narrowed, allowing the nail to pass medial to the blocking screw, thereby correcting the coronal alignment. As a rule of thumb, blocking screws are placed anterior to the nail when the distal fragment is flexed medial to the nail for a valgus deformity, and lateral to the nail for a varus deformity. These screws are usually placed on the concave side of the deformity in contact with the intramedullary implant.[31]

Deformity is not spontaneously corrected in the z-axis (i.e., rotation and length). Distraction may result from too much traction or incomplete distal reaming. Conversely, the risk of shortening increases with segmental comminution or oblique fracture patterns. Length malalignment can be avoided by assessing secondary radiographic signs of length intraoperatively. For example, assessing fragment reduction can help determine length. Excessive overlap of fragments suggests shortening, and gaps suggest lengthening. To allow for length adjustment, the length should be assessed after locking one end of the nail but before locking the other end. Immediately after the procedure, the length of both lower extremities should be compared by holding the limbs in a symmetrical position while comparing the position of the medial malleoli and heel. Limb-length discrepancies of less than 1 cm are not usually clinically significant. Early recognition of length malreduction greater than 1 cm should usually be corrected.

Rotation

Malrotation of the femur is more common than deviations in axis or length following intramedullary nailing (IMN).[31] Various techniques have been described to avoid common rotational deformities.[32-36] To establish correct rotational alignment, the surgeon must determine the rotation of the proximal fragment, and lock the distal fragment in a rotational alignment that matches that of the proximal fragment. Furthermore, it is important to recognize the deforming forces placed by muscle tone.

Several radiographic techniques exist that can help determine femoral rotation.[37-39] These methods use the profile of the lesser trochanter on an anterior-posterior (AP) hip radiograph, femoral condyles on a lateral knee radiograph, or the thickness of the femoral shaft cortices as reference points. For example, an AP radiograph showing a prominent lesser trochanter indicates that the proximal fragment is externally rotated from its anatomic position. Once a true AP view has been obtained at the hip, the distal femoral shaft should be rotated to match the position of the proximal fragment (until the patella is superimposed over the lateral femoral condyle). Regardless of the technique used, surgeons must compare rotation and alignment of the limbs after femoral nail placement before and after locking.

A rotationally-reduced femoral shaft fracture results in symmetrical hip range of motion. Postoperative assessment of hip rotation provides a physical examination tool to assess rotational reduction. Rotational differences of less than 20 degrees are generally well tolerated. During postoperative ambulation, the foot-progression angle should be checked to assess rotational reduction of the fracture. If found early, femoral rotation greater than 20 degrees can be corrected by return to the OR and unlocking the nail distally, de-rotating the fracture site with manipulation, and relocking the nail in its reduced position. Rotational malalignment that is found after callus formation should not be corrected until the fracture is healed. Once healed, a de-rotational osteotomy and exchange nail can be performed.

There is also the potential to mal-rotate the nail relative to an anatomically-reduced fracture. Nails are designed to be placed in the correct anatomic position, which allows for the nail to follow natural femoral bowing and for safe placement of interlocking screws. A malrotated nail can cause fracture-site deformity, intraoperative comminution, or problems with the path of locking screws.

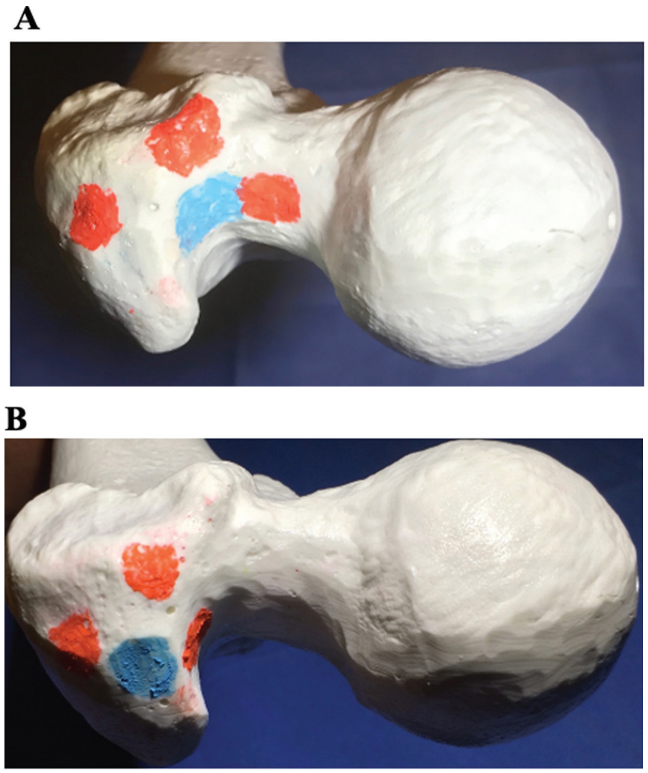

Figure 2. *Correct starting point (blue) and common entry point errors (red) for A) piriformis entry and B) trochanteric entry. In the piriformis entry, the most medial red entry increases the risk of damage to the medial femoral circumflex artery and likely avascular necrosis. The anterior and lateral red areas will result in apex anterior and lateral deformities, respectively.*

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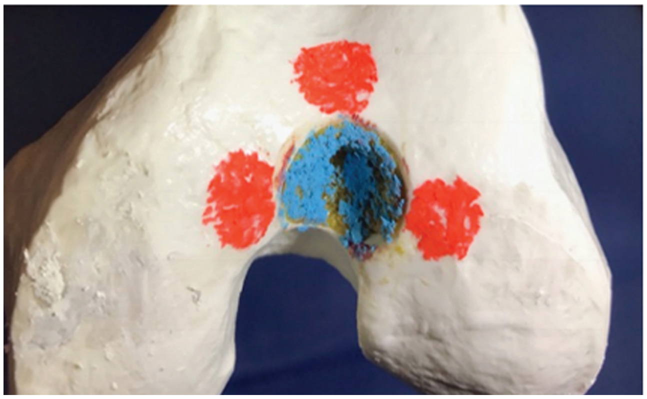

Figure 3. *Distal femur with the correct retrograde entry site in blue, and common mistakes in red. Starting lateral, anterior, or medial will cause apex lateral, anterior, and medial deformities, respectively.*

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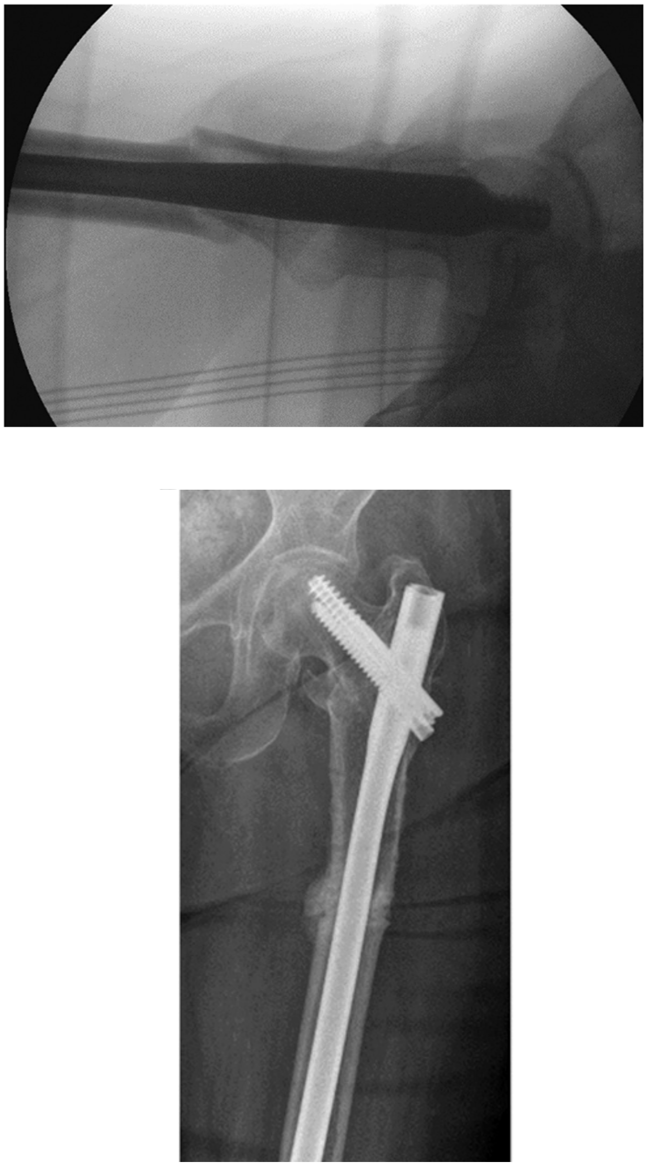

Figure 4. *Radiographs of a femur after antegrade nailing. A) Lateral view shows starting point that is too anterior, resulting in an apex anterior deformity. B) Anteroposterior view shows starting point that is too lateral, resulting in an apex lateral deformity.*

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Figure 5. *Failure to irrigate may result in complications such as heterotopic ossification, as found superior to the greater trochanter in this femur.*

Incorrect Starting Points

Executing the correct entry site is important for each patient to avoid malreduction. Piriformis (Figure 2A), trochanteric (Figure 2B), and "trochaformis" entry points are used in antegrade nailing.[13] A retrograde nail is placed in the center-center position in the sagittal and coronal planes of the distal femur. Because the entry points are most often made percutaneously, there is potential for aberrant starting points. The femoral shaft fracture should be reduced before drilling the entry site for retrograde nails. In retrograde nailing (Figure 3), apex anterior fracture deformities are caused by the pull of the gastrocnemius muscles. In antegrade nailing, a starting point anterior to the intended starting point creates an apex anterior deformity (Figure 4A). In contrast, an apex lateral deformity is caused by a starting point that is too lateral (Figure 4B).

REAMING ERRORS

Reaming the endosteum creates a larger intramedullary canal, allowing the nail to act as a load-sharing device (Figure 5). Reamers have the potential of becoming confined in the intramedullary canal. To prevent this complication, surgeons should use sharp, deeply-fluted reamers, advance slowly, keep it spinning, and increase in 0.5-mm diameter increments. It is generally recommended to ream to 1.5 mm over the desired nail diameter when good osseous chatter is encountered. Inadequate reaming is associated with nail incarceration, prolonged operating time, and inadequately small-diameter nails. Excessive reaming has been associated with increased pulmonary complications, reamer incarceration, and prolonged operating time. Interestingly, nail diameter has not been associated with risk of nonunion.[40] Because a 10-mm nail is considered standard for the treatment of acute femoral shaft fractures, surgeons should generally expect to ream to 11.5 mm.[40] However, the patient's specific anatomy should be considered prior to making this decision.

IMPLANT INSERTION ERRORS

The native femur is not a straight column, but rather has anterior and lateral bows.[41] Bowing is measured by radius of curvature (ROC). The ROC may change in a lifetime, with studies demonstrating that anterior bowing may increase over a lifetime in female patients, but not in male patients.[42,43] When choosing an implant, the ROC of the nail and femur should be matched. The most common entry error occurs when the nail is too straight in relation to the bowed femur. In this situation, the distal end of the nail is on the anterior cortex and may penetrate the cortex. This increased stress can cause thigh pain, or even a fracture. The trochanteric entry point is more lateral than the piriformis fossa and not in line with the medullary canal. Therefore, using a piriformis entry with a trochanteric nail may result in an apex lateral deformity.

Nail diameter and length should be compatible with the patient's anatomy. Usually, the nail should be 1 mm smaller than the medullary canal. Nail length should be accurately measured intraoperatively. In antegrade nailing, the nail should end at the center of the patella or at the distal femoral physeal scar, and should not be left proud proximally to avoid irritation of the hip musculature. Retrograde nails should be recessed 10 mm beneath the articular cartilage to avoid patella injury. To avoid a stress riser in the proximal femur, a retrograde nail should end at or proximal to the lesser trochanter. Generally, using a longer nail increases the likelihood of symptomatic hardware, whereas under sizing the nail increases the risk of periprosthetic fracture.

Locking the nail proximally and distally maintains alignment in length, rotation, and translation, which facilitates healing. Locking screws should be bicortical to maintain reduction. Proximally mounted guides are not effective at accurately placing distal locking screws. The authors use "perfect circle" fluoroscopic technique for distal locking.[44] Several techniques can help place distal locking screws, including radiolucent drills and navigation. False passes should be avoided because they increase operating time, implant failure, and radiation exposure while decreasing bone strength. Many nail designs have a dynamic interlocking screw slot. One locking screw should be placed through the end of the slot away from the fracture to allow later dynamization by simply removing the other locking screw in the round hole. Proximal locking with nail mounted guides is generally effective, but problems do occur. To avoid this technical error, make certain the correct guide is firmly attached to the nail and that the guide aligns with holes in the nail ("drop test" on the back table). Especially in patients with large body habitus, it is essential to ensure that the drill guide is completely touching the lateral cortex of the femur before inserting the drill bit.

PAIN MANAGEMENT ERRORS

Femur shaft fractures are painful injuries. The current narcotic overdose epidemic involves additional deaths stemming from long-term opiate use.[45,48,49] The death count continues to rise, and the role of physicians remains a focus of study. Therefore, orthopaedic surgeons must balance the need for adequate postoperative analgesia with the risk of narcotic addiction. We recommend using intravenous narcotic pain medications for up to 48 hours postoperatively, because a short duration of narcotic use has little addictive potential.[45] Pain treatment should be multimodal rather than solely relying on opiates.[46] After 48 hours, oral narcotic pain medications should be used. After 2 weeks, pain medications should be strictly non-narcotic oral analgesics (e.g., acetaminophen). The authors do not recommend that patients are prescribed narcotic pain medications beyond 6 weeks postoperatively due to the potential for addiction and undesired side effects. Furthermore, the authors suggest standardized postoperative pain regimens to limit narcotic duration while emphasizing alternative pain- controlling techniques.[47]

At this institution, postoperative pain protocols following femoral shaft intramedullary nailing includes narcotics as described above, and scheduled acetaminophen, gabapentin, 3 days of scheduled intravenous ketorolac, and as-needed muscle relaxants (i.e. baclofen, cyclobenzaprine). The authors also strongly recommend the use of preoperative or intraoperative nerve blocks, as these have been demonstrated to reduce postoperative pain and narcotic consumption.[50]

There has previously been concern that nonsteroidal anti-inflammatory drugs (NSAIDs) increase the risk of nonunion following fracture fixation. However, more recent literature has not demonstrated any increased risk of delayed union or nonunion. The authors therefore recommend that NSAIDs be used in the postoperative pain regimen following primary femoral shaft nailing.[51]

IMPLANT REMOVAL ERROR

Most femoral shaft fractures heal uneventfully after treatment with statically locked medullary nailing, making routine removal of locking screws unnecessary. However, some patients develop delayed union due to soft-tissue injury (e.g., open fractures), comorbidities (e.g., smoking or metabolic bone disease), treatment irregularities (e.g., open or unreamed nailing), delayed weight bearing, and poor nutrition.[52] When a fracture has not shown signs of healing at 4 months postoperatively, the authors recommend dynamization of the nail by removing locking screws from one end of the bone. This ambulatory procedure is performed with the patient under sedation and local anesthesia. There is typically sufficient callus formation to prevent rotation or significant shortening at the fracture site. A small amount of shortening (1 mm to 2 mm) after dynamization is helpful to promote fracture healing and is well tolerated.

The most common dynamization problems result from failure to dynamize delayed unions and removal of locking screws from the wrong end of the nail. For antegrade nails, the screws furthest from the fracture site should be removed. For retrograde nails, the proximal locking screws should be removed. Removal of the distal locking screws may allow the nail to move within the distal fragment and become prominent within the knee joint. Less commonly, the nail may no longer be in line with the original entry point. If the nail later requires removal, then the creation of a new starting point is necessary. This can be especially undesirable when removing retrograde nails through the knee joint.

Implant removal after fracture healing and remodeling is controversial. Proponents of the procedure suggest that it is easy and can reduce persistent pain. It may also be helpful, if not necessary, in allowing for future procedures (i.e. total hip arthroplasty). However, studies have reported that removal is frequently complicated and often does not result in reduced pain.[45] The authors recommend implant retention unless clearly indicated by recalcitrant infection or symptomatic prominence. The nail should be removed between 12 months to 24 months postoperatively, if necessary. The risks of earlier removal include occult, delayed union, and loss of alignment. The risks of later removal include nail incarceration, removal difficulty, and intraoperative fracture. The nail type and necessary equipment for removal should be identified in advance.

This review provides characteristic problems, complications, and subsequent solutions related to nailing femoral shaft fractures in adults. The importance of empirical medical evidence can never be overstated; however, clinical expertise is also of the utmost importance. It is no coincidence that numerous cultures across the globe have terms regarding those who have mastered their craft; without formal medical evidence, the wisdom and understanding of the "guru" and "virtuoso" is accepted. In this light, the knowledge gained from an extensive career in orthopaedics also provides useful and practical information that is invaluable.

SUMMARY

Nailing of femoral shaft fractures is an effective treatment with excellent outcomes. However, there are various under-appreciated potential complications and technical problems unique to femoral nailing that commonly occur (Table 3). Recognition of these potential problems can help orthopaedic surgeons avoid these issues, deal with them when they occur, and realize the potential of this treatment option to efficiently restore full function to patients with femoral shaft fractures.

***Table 3**. Problems and Pearls Associated with Nailing of Femoral Shaft Fractures in Adults*

Number	Problems	Pearls
1	Missed associated injuries	Vigilance*
2	Suboptimal surgical timing	4 h-24 h after injury is optimal
3	Malreduction Entry-point error Translation/angulation	Entry point Precision Retrograde Antegrade Blocking screws
4	Reaming errors	1.5 mm of extra bone
5	Implant error	Match ROC to bone
6	Poor pain management	Limit narcotic use at 2 weeks
7	Removal errors	Dynamized delayed unions Rare removal of nail 12 month- 24 month window

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