Antegrade Nailing of Femur Shaft Fractures: A Review

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Abstract

Rigid intramedullary (IM) nailing is an effective procedure for treating fractures of the femoral shaft. Despite the existence of alternative devices and techniques (eg, unreamed nails, flexible nails, plates, external fixation, and traction), the use of rigid reamed nails has shown excellent healing rates, return of function, alignment, and low complications. This type of nail has been used in an antegrade approach to the entry site of the fracture, resulting in successful treatment. We describe indications, contraindications, and surgical techniques of antegrade IM nailing associated with our personal experience and published results. We provide pearls and pitfalls to assist orthopaedic surgeons in the effective implementation of this approach. A complete understanding and awareness of the various techniques related to antegrade IM nailing can help successfully treat most femoral shaft fractures in adults.

Introduction

Reamed, locked, rigid intramedullary (IM) nailing can effectively treat most fractures of the femoral shaft.[1] IM nailing has allowed stabilization of the bone without direct exposure of the fracture site, thus preserving the soft-tissue integrity and healing potential of the region around the fracture.[1] The procedure has also restored length, alignment, and rotation of fractured bones, with rapid return of function and early, reliable healing.[2-6] The nail is a load-sharing device that allows cyclic loading with ambulation and thus low risk of implant failure. Use of special instrumentation has reduced surgical exposure and operating times.[7]

Alternative treatment options include use of unreamed nails, flexible nails, and plates; external fixation; and traction.[8] However, use of rigid reamed nails generally results in improved healing rate, return of function, bone alignment, and postoperative complications.[9,10] Alternative techniques are reserved for specialized situations. Since the introduction of medullary fixation by Küntscher in 1939 at the University of Hamburg, associated techniques have been refined.[11]

For decades, physicians successfully used antegrade IM nailing through the piriformis fossa at the junction of the greater trochanter and neck of the femur.[12] The piriformis entry site is co-linear with the medullary canal of the femur shaft and was appropriate with use of large diameter, open section, stiff, straight nails.[11,13] To provide better control of nail rotation and length, locking screws were developed and allowed use of nails that are flexible, smaller in diameter, thinner walled, closed section, and curved.[11,13] This change in nail design allowed easy surgical access to the tip of the greater trochanter, as opposed to the piriformis fossa.[14-17]

Subsequently, the trochanteric entry site has become a widely used approach for antegrade IM nailing, although the piriformis entry point is preferred by some providers and in special circumstances.[18] Starr et al[19] reported no difference between the two entry points in union rate, blood loss, intra- and postoperative complications, and long-term functional outcome scores. Ricci et al[15] noted that use of a trochanter entry-point nail with a lateral bend, compared to piriformis entry-point nails, resulted in decreased fluoroscopy and operating times (especially when used in patients with large body habitus) and decreased risk of heterotopic ossification (15% vs 21%). A study by Tupis et al[16] advised against use of a straight nail in the greater trochanter owing to increased strain levels and thereby potential iatrogenic fracture. The study also reported an increase in varus malalignment when using a straight nail with a trochanteric entry site. The piriformis entry site is much closer to the medial femoral circumflex artery than the trochanteric entry point. Owing to the development of avascular necrosis of the femoral head, using the piriformis entry site in adolescents is avoided.[20,21]

In the current paper, we combine the results of our experience with those of published studies. We describe the indications, contraindications, and current techniques for use of antegrade IM nailing of femoral shaft fractures. We also examine differences between the piriformis and trochanteric entry sites. Our review of surgical technique includes positioning, incision, entry site, fracture reduction, reaming, nail insertion, locking screws, wound closure, and postoperative management. We present pearls and pitfalls of antegrade IM nailing to assist orthopaedic surgeons in effectively using the technique for treating femur shaft fractures.

Indications and Contraindications

Table 1 shows general indications, general contraindications, and relative contraindications of antegrade approach for treating femur shaft fractures with IM nailing.[22]

Surgical Technique

Positioning

Antegrade IM nailing can be performed in the supine or lateral position. The supine position is easier to set up but the entry site can be difficult to access due to the soft tissue and chest wall. Lateral position is more complicated for airway access for anesthesia.[23] It is also more difficult to assess rotational reduction in the lateral position, and fluoroscopic visualization of the entry site is more difficult.[23,24] The lateral position requires more time to set up, but reaming and nail insertion are much easier.[25] Gravity retracts the soft tissue and the chest is far from the entry-site path.[25] Hip adduction to gain proximal femur access is facilitated. The choice between a supine or lateral positioning remains primarily based on individual preference. The decision is influenced by the fracture pattern and the patient's other associated injuries.[23,24]

A study by Firat et al[25] reported less operating time and fluoroscopy time with use of a supine approach. Lateral positioning has been associated with a higher risk of external rotation deformity, with more difficult reductions of comminuted fractures.[26] Apostle et al[23] reported no difference between the two with regards to mortality or admission to the intensive care unit (ICU) in patients with an injury severity score of ≥ 18. This study, however, reported that in a subgroup of patients who had an abbreviated chest injury score of ≥ 3, use of intraoperative lateral positioning had a significant protective effect against ICU admission. This was thought to be caused by a greater lung functional residual capacity in the lateral position compared to the supine position.

The patient is placed on a fracture table and lies with adduction of the trunk and affected extremity. The unaffected limb is moved out of the way of the fluoroscope by extending or flexing and abducting at the hip. Traction is applied through a skeletal pin or foot holder against a perineal post.

For lateral position IM nailing, the bovie ground pad is

Table 1. General indications, general contraindications, and relative contraindications for intramedullary nailing in treating femur shaft fractures

General indication[a]	General contraindication	Relative contraindication (to antegrade nailing)
Aged 18 years and older (almost always)	Aged 11 years and younger[c]	Severe open fractures[e]
Aged 14 to 18 years	Active infection	Severe soft-tissue injury of hip
Shaft with distal or proximal extention	Disorders (eg, osteopoetrosis) that prevent nail to enter medullary canal	Pre-existing implant blocking antegrade medullary access
Pathological fractures[b]	Multiple trauma (ISS more than 25)[d]	Fractures extended into the distal femur (metaphyseal or articular)

ISS, Injury Severity Score.
[a] Patient-based variables (eg, the patient is aged 18 years and older).
[b] Ambulation even with delayed bone healing; stabilizes entire shaft.
[c] The medullary diameter is too small to accept the implant.
[d] Includes incompletely resuscitated or hemodynamically unstable injuries, particularly with evolving or uncompensated chest injury. May be an indication for using damage-control techniques.
[e] External fixation may be preferred.[37]

applied to the thigh and a compressive wrap applied from toe to hip. The patient is placed on their unaffected side and the trunk supported with bean bag and contralateral axillary roll. The contralateral limb is extended at the hip while the fractured limb is flexed and adducted to allow independent fluoroscopic visualization of the broken femur. Traction is applied through the fracture table with counter-traction by a perineal post. Reduction is confirmed fluoroscopically.

Incision

An oblique 6 cm incision is made in line with the greater trochanter starting 6 cm proximal to the trochanteric tip. The fascia of the abductor muscles is exposed and then divided in line with its fibers. The incision in the abductors is kept as small as needed to insert the instruments to the entry point on the proximal femur.[27,28]

Entry Site

The tip of the greater trochanter is palpated and a guide pin is placed under fluoroscopic bi-planar control. The guide-pin is advanced 5 cm into the proximal femur in line with medullary canal and position confirmed on bi-planar fluoroscopy. Küntscher's awl technique can still be used effectively[11]; however, a guide pin is now standard. A cannulated entry reamer opens the proximal femur 5 cm into the medullary canal. A sleeve helps minimize muscular and skin damage. The piriformis fossa is located at the junction of the neck and greater trochanter slightly anterior to mid-coronal (Figure 1). The trochanteric entry point is at the tip of the greater trochanter (Figure 2).

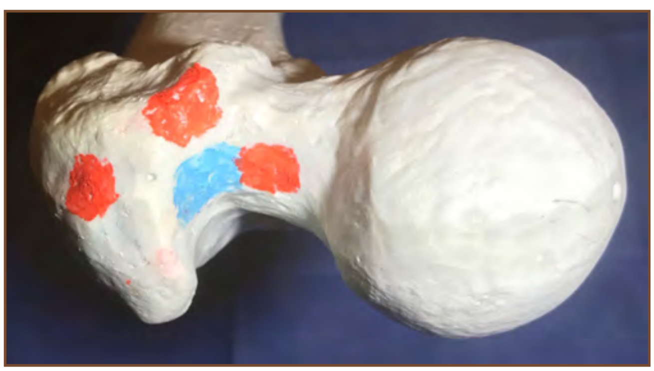

Figure 1. Photograph of the recommended piriformis entry site (blue), with eccentric (ie, not recommended) locations in red.

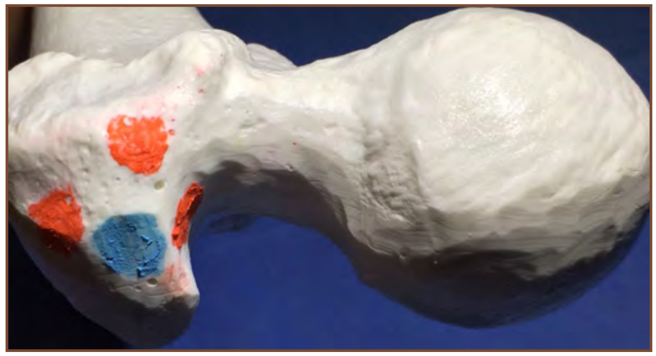

Figure 2. Photograph of the recommended trochanteric entry site (blue), with eccentric (ie, not recommended) locations in red.

Fracture Reduction and Ball-Tipped Guide Passage

The fracture is distracted and aligned with traction and external pressure. A ball-tipped guide rod is inserted into the cannulated reduction tool ("finger"), and both are inserted into the proximal fragment of the femur to the level of the fracture. The fracture reduction tool can be used as a lever to manipulate the proximal fracture fragment into a more precisely reduced position.[27,28] The curve at the tip of the "finger" helps direct the ball-tipped guide across the fracture site into the medullary canal of the distal fragment under fluoroscopic control. The reduction tool is removed. The ball-tipped guide is advanced distally to the center of the distal physeal scar on AP and lateral fluoroscopy. The measuring sleeve is slid down until it aligns with the entry point on the surface of the proximal femur to measure the length of the nail. The ball-tipped guide is advanced 1 cm further into the distal femur to avoid displacement during subsequent reamer removal.

Medullary Reaming

Serial reaming of the femoral canal is started with an end cutting reamer (9-mm diameter). Reamer rotation speed is maximized while the reamer is slowly advanced all the way to the distal physeal scar and then slowly extracted while reaming. The reaming is continuous and never in reverse. The reamer tip is exchanged and the steps repeated in 0.5-mm increments until isthmic cortical chatter is encountered, usually at about 11 mm. An obturator is used during reamer exchange to maintain the guide position. It is recommended to use a nail at least 1 mm less in diameter than the maximum diameter reamed to facilitate easy passage of the nail.[29]

Nail Insertion

The appropriate sized nail is selected and mounted onto the driver assembly. Fracture reduction is confirmed clinically and radiographically. In supine position, rotation of the limb is adjusted by comparing it with the uninjured leg and by imaging to reveal the profile of the lesser trochanter to rotationally align the distal fragment with the proximal fragment.[28,29] The patella generally should point straight anteriorly. Assessment of rotation is more difficult but equally important with lateral position nailing.

The nail and driver assembly is placed over the guide wire and into the femoral entry site. The nail is advanced to the fracture site with gentle blows while monitoring the guide wire to ensure that it does not advance with the nail. The nail should advance with each blow, which is especially important as the tip of the nail passes the fracture site. Reduction is confirmed as the nail is passed across the fracture. The guide rod is removed. The nail is seated to the distal physeal scar with the proximal end of the nail at the entry site. Length and rotation of the nail and the limb are maintained and confirmed during nail insertion.[28]

Locking

Placement of locking screws in both the proximal and distal fragment is recommended in nearly all cases.[7,26] Some nail systems have two or more distal interlock screw options; one may be oblong or a "slot" for a dynamic locking option.[30] A locking screw placed through the distal aspect of the dynamic locking slot maintains rotation only. The second locking screw in the static round hole maintains length and angular alignment.[30] If delayed union occurs, the static locking screw can be removed. The retained dynamic locking screw allows slight shortening to facilitate healing but prevents excessive shortening and maintains stability against rotation and angulation. More recent studies indicate that dynamization with a screw preserved in the dynamic locking hole is associated with a higher union rate when compared to removing two static inter-lock screws in patients with delayed bony union. This union rate is highest when dynamization was performed between 10 and 24 weeks from the time of the index surgery according to a study by Huang et al.[31]

Proximal locking is performed through a nail mounted guide. The most common pattern is a single oblique screw from proximal lateral, through the nail, to the distal medial cortex at the lesser trochanter. Some nail designs have one or two transverse screws at the level of the lesser trochanter. Reconstruction nails are available which provide cephalad fixation into the femoral head and neck when required in proximal fractures.[32] One must confirm that the nail tip is at the cortex of the greater trochanteric or piriformis entry point immediately prior to proximal locking screw placement.[31] An incision is made where the drill sleeve meets the skin. The drill sleeve is seated down to bone. Using the specific drill bit, a hole is drilled through the lateral and medial cortex. The depth gauge is utilized to determine the length of the screw.

A variety of techniques are available for distal locking. Nail mounted guides have not generally been successful.[7] We, like most surgeons, use a freehand technique with fluoroscopic guidance. Alternative techniques for distal locking have also been reported. A radiolucent drill is particularly useful when learning the technique of distal locking. A hand held electromagnetic targeting system has been introduced, which may facilitate the insertion.[33] This system has been shown to reduce radiation exposure and operating time and is equivalent in accuracy when compared to the free hand technique according to two recent studies by Chan et al.[34]

Correct length and rotation of the femur is confirmed immediately prior to distal locking. Using lateral fluoroscopy, a perfect circle of the distal locking hole in the nail is obtained and the overlying skin is marked. A 2-cm longitudinal incision is made and the lateral fascia is divided in the mid coronal plane in line with its fibers.[33] The periosteum of the lateral cortex of the femur is elevated with a Freer elevator. The tip of the drill bit is centered over the hole on fluoroscopy with the drill handle anterior to the thigh. The drill is rotated parallel to the beam and perpendicular to the nail and a hole is drilled through the lateral cortex to the endosteum of the medial cortex. Length is measured from the scored bit and 5 mm is added. The medial cortex is drilled and the screw is then placed. A second screw can be placed in similar fashion.

Wound Closure

The wounds are irrigated to remove reamings.[22] The fascia of the abductors, the subcutaneous tissue and the skin are each closed. The locking incisions skin layer is closed.

Postoperative Management

At the completion of the case the limb is assessed for length and rotation. A ligamentous examination of the knee is performed and recorded. The femoral neck should be radiographically inspected for fracture by bi-planar fluoroscopy in internal and external rotation.[3] Plain radiographs are obtained of the entire femur in two planes and reviewed to assess fracture reduction, implant position and the absence of intraoperative complications. Postoperative management of femoral shaft fractures depends on the extent and severity of other injuries.[34]

Most isolated closed fractures can be started with weight bearing as tolerated immediately. Crutches or a walker are used for the first 6 weeks. Restricted weight bearing has been recommended in non-compliant patients, those with extensive comminution of the fracture or other significant lower extremity articular injuries.[34] Hip and knee range-of-motion and strengthening exercises are started after 2 days. Routine follow-up consists of a 2-week clinic visit with removal of skin sutures. Subsequent follow-up should occur every 6 weeks until full function is observed with radiographs until union, typically at 5 months. A final clinic visit occurs at 1 year after the injury. Nail removal is rarely indicated.

Outcomes

IM nailing has resulted in restoration of both form and function and produced remarkably good short- and long-term results, with low complication rates.[6] The reported results of reamed nailing have been superior to those of other methods for treating closed and open type I, II, and IIIA fractures.[8] Almost complete return of hip and knee motion with a union rate of more than 95% can be expected.[12,21] Infection rates have been minimal (< 1%) for closed fractures. IM nailing of severe open fractures has higher infection rates, but so do other treatments of this injury.[8] Systemic complications and death rates associated with patients with femur shaft fractures have decreased in the past 25 years because nailing techniques have improved.[12,35,36] The early return to ambulation prevents most of the problems of prolonged recumbent status, including disuse atrophy, stiffness, weakness, deep vein thrombosis, and pneumonia.[37] Hospitalization is relatively short and many patients are able to return to work while the fracture heals.[37,38]

Pearls

Based on our personal experience in using antegrade approaches with IM nailing, our noted "pearls" or helpful considerations include:

1. It is important to ream at least 1 mm more than the selected nail diameter to accommodate for the natural curvature of the femoral canal and ease of insertion. The nail should pass easily with light tapping with a mallet. If resistance is encountered, remove the nail and ream an additional 1-2 mm.[37]
2. Use the guide pin with bi-planar fluoroscopy to make sure the entry point is exactly correct before reaming. "Eccentric" starting point may result in fracture malreduction,[4] iatrogrenic comminution, nail malposition or nail breakage (Figure 3).
3. Make sure the fracture is reasonably aligned prior to entry reaming for IM nailing of sub-trochanteric fractures. If the entry channel is created with the proximal fragment flexed and apex anterior angulation of the subtrochanteric fracture site, that same deformity will recur with nail placement (Figure 4).[32]

Figure 3. Anteroposterior radiograph of the femur, showing effect of an eccentric (too lateral) trochanteric entry site. Notably, the placement results in varus (apex lateral) mal-reduction of the femur shaft fracture.

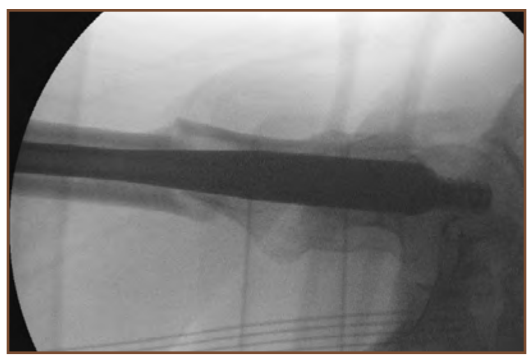

Figure 4. Lateral radiograph of the femur, showing effect of an eccentric (too anterior) piriformis entry site. Notably, the placement result sin extension (apex anterior) malreduction of the subtrochanteric femur shaft fracture.

4. Withdraw the guide wire after the nail has entered the distal fragment. Otherwise the guide wire may be driven through the distal femur or become stuck as the nail is seated.
5. If the distal locking screw lateral entry site is anterior to the coronal midline, the nail or fracture is likely internally mal-rotated and should be corrected before proceeding.

6. If the fracture is distracted after nail insertion then seat the nail to the physeal scar distally and perform distal locking. Release traction and backslap the nail to impact the fracture and then perform proximal locking.
7. For proximal and mid-shaft fractures, only one distal locking screw is required. In more distal fractures, two screws should be used to prevent angulatory deformity.
8. Note the specific implants used in the operating note, particularly if any special instruments are needed. This will facilitate removal or revision.
9. Aggressive intravenous or intramuscular management of pain is appropriate for the first 48 hours postoperatively. Orally, analgesia is appropriate for 14 days postoperatively. Avoid chronic narcotic problems after 2 weeks postoperatively.

Pitfalls

Based on personal experiences and results of published studies, our noted "pitfalls" (ie, complications associated with antegrade locked rigid IM nailing) involve associated injuries, wrong measurements of length, and difficulties with reaming, nail insertion, locking, and rehabilitation.

Associated Injuries

1. Late diagnosis of associated femoral neck fracture. There is a 5% incidence of associated femoral neck fracture, and many of these are not diagnosed initially.[12]
2. Iatrogenic femoral neck fracture.
3. Late diagnosis of other injuries (eg, tear of the knee ligament).

Wrong Measurement of Length

1. Unfamiliarity with the measuring device of the system used.
2. Distraction or shortening at the fracture site during length measurement, resulting in nail of the wrong length (too short or too long).
3. Not maintaining or confirming the distal location of the ball-tipped guide during length measurement.
4. Not ensuring that the measuring device is at the entry cortex (the measuring device can get caught in the soft tissue or advanced inside the entry canal).
5. Choosing the next longer nail when optimal length is between available sizes, resulting in prominent nail. Shorter nail is generally preferred.

Reaming

1. Never use a reamer in the reverse mode as it may unwind and break.
2. Failure to use a ball-tipped guide, which is required to extract a stuck reamer.
3. Advancing the reamer too rapidly. The reamer may become stuck or spiral down the femur resulting in a "rifling" effect that leads to rotation of the nail or failure to advance the nail during insertion.
4. Using shallow fluted or dull reamers, which increase heat and pressure and pushes medullary contents into the circulation and causes pulmonary dysfunction.
5. Failure to maintain reasonable reduction during reaming, which results in increased risk of comminution at the fracture site. Eccentric reaming also leads to malreduction.
6. Failure to use an obturator (or other method) to maintain position of the guide during reamer extraction, which may result in loss of intramedullary position of the ball-tipped guide. This can lead to extramedullary reaming (very undesirable) or considerable time loss in replacement of the ball-tipped guide (undesirable).
7. Holding the ball-tipped guide with the gloved hand during reamer extraction. The ball-tipped guide can spin, wrapping up the glove and contaminating both the reamer and the ball-tipped guide, adding an hour to operating time while new sterile instruments are obtained. A Kocher clamp should be used.
8. Failure to adequately ream distally, which can cause distraction of the fracture site during nail insertion.
9. Extensive reaming in severely traumatized patients, which may cause pulmonary decompensation. Damage control techniques may be preferable.

Nail Insertion

1. Incorrectly mounting the nail relative to anterior and lateral bow. The surgeon (not a scrub technician) should confirm alignment before insertion. Trochanteric nail systems have right and left designs.[39]
2. Failure to correctly identify the correct orientation and diameter of the interlocking guides, holes, and drill bit diameter before insertion.
3. Using a nail of larger diameter than reamed.
4. Striking the drill guide assembly with the mallet. This deforms the guide which is no longer aligned to the holes in the nail. Only the insertion or extraction attachment should be struck.
5. Failure to advance the nail with each blow. The next strike may comminute the fracture or incarcerate the

nail. Impact sound will also change if the nail is not advancing.
6. Using excessive force advancing the nail, which may result in fracture comminution or nail incarceration.
7. Failure to maintain rotation of the nail during insertion will result in oblique mal-positioned locking screws and cause malreduction of the fracture through loss of anatomic anterior bow.
8. Failure to maintain reduction (especially length and rotation) during nail insertion, which results in malunion.
9. Failure to confirm seating of the nail at the time of locking, which can lead to prominence of the nail into the hip musculature.
10. Failure to confirm central position of the guide wire, reamer, and nail within a short distal fragment resulting in angulatory mal-union.
11. Mismatch radius of curvature between patient and nail. Specifically using a straight nail (large radius of curvature) in older patients with a bowed femur (small radius of curvature). As a result, the nail penetrates through the anterior cortex distally.

Locking

1. Failure to establish a stable alignment for the limb, resulting in motion during locking screw placement and subsequent malposition of the screws.
2. Failure to remove the guide rod prior to drilling for locking screws.
3. Drilling a cortical hole near but not directly over the hole in the nail. This makes subsequent correct placement difficult and weakens the bone.
4. Placement of screws that are too long, resulting in medial irritation, or too short, resulting in angulation.
5. Failure to fully seat the screw head against the near cortex, resulting in soft-tissue irritation. This is especially common in screws with an increased diameter of thread at the neck of the screw.
6. Losing the screw from the screwdriver into the soft tissue during insertion. (See Pearl 8.)
7. Attempting to use nail-mounted guides for distal locking. These are not generally reliable because the nail deforms somewhat during insertion.
8. Failure to place both proximal and distal locking screws in rotationally or length unstable fracture patterns (most fractures).
9. Placement of locking screw in the proximal (wrong) end of the dynamic slot.
10. Failure to assess length, rotation and stability at the end of the case. This is the time when it is easiest to correct any problems.
11. Failure to assess other injuries at the end of the case (femoral neck fracture, knee ligament injury, etc). This is the best time to diagnose these injuries and determine a plan of treatment.

Rehabilitation

1. Failure to recognize abnormal length or rotation during early ambulation when it is relatively easy to correct by revision of the nail.
2. Failure to recognize occult fractures of the femoral neck when the patient begins to ambulate.[40]
3. Failure to match patient physical activity to the postoperative levels of stability and healing. Too much activity too soon can result in loss of fixation, fracture, or bending of the nail. Excessive restriction of activity can result in stiffness, weakness, and delayed union.
4. Failure to recognize delayed union early when it is easiest to treat by simple dynamization.[9]
5. Prolonged use of narcotic analgesics, resulting in chronic dependency problems.[41]

Conclusion

Antegrade locked rigid IM nailing is an effective method for treating femur shaft fractures. Piriformis and trochanteric entry sites can both be used as an approach. Knowledge of implant design, specific techniques, and treatment pearls can facilitate the procedure and help avoid problems and pitfalls.

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Conflict of Interest

The authors report no conflicts of interest.

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