Locked Femoral Nailing

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Abstract

Locked intramedullary nailing has become the standard of care for most femoral fractures. Originally designed to prevent rotation and shortening in comminuted fractures of the midshaft, its application has been extended proximally and distally to nearly all femoral fractures from the lesser trochanter to the supracondylar area. Achieving a closed reduction and selecting the proper starting point in the piriformis region are crucial to a successful result. Following the proper surgical technique for the specific nail used is more important than nail material or design. Large-diameter reamed nails provide greater strength than unreamed nails. Static locking has been shown to yield nearly the same high union rates as dynamic locking and is now the accepted standard. Distal targeting of the interlocking screw remains the most difficult aspect of the surgical technique; most surgeons prefer freehand targeting with a sharp trocar. Second-generation (reconstruction) nails, with screws directed toward the femoral head, has extended the indications for locked nailing proximally to subtrochanteric fractures and combined femoral neck-shaft fractures.

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Traditional treatment of femoral shaft fractures has been traction or cast bracing. Unfortunately, the use of these techniques typically led to a high rate of malunion and knee stiffness.[1,2] The advent of plate fixation improved both alignment and knee motion but resulted in a higher rate of infection, nonunion, and implant failure. Closed Küntscher nailing[3] allowed both excellent function and an extremely low nonunion and infection rate.

Only two problems remained: shortening and rotation.[4] The solution to these problems appeared to be the development of an intramedullary nail with holes for screw fixation. Modny, Halloran, and Huckstep all developed this concept,[5] but the first published report detailing the use of an interlocking (locked) femoral nail came from Gerhard Küntscher.[6] Use of the locked femoral nail inserted with a closed technique has become the standard of care for treatment of femoral shaft fractures but demands experience on the part of the surgical team.

Indications

Interlocking nails were initially indicated for femoral fractures with instability of length, rotation, and angulation. Originally, ideal indications were femoral shaft fractures with Winquist type III comminution (greater than 50 percent of the cortex comminuted) and Winquist type IV fractures (segmental comminution).[7] As experience was gained with these locked nails, indications were extended to segmental fractures, spiral fractures, fractures below the lesser trochanter, and infraisthmal fractures, including some minimally displaced fractures extending into the knee.[8-11]

In a large series, Brumback et al[12] clearly demonstrated that the degree of comminution could not always be anticipated preoperatively, and that either missed fractures or comminution caused by surgery led to shortening and rotation in an additional 10% of patients treated with unlocked femoral nailing. To prevent these complications, their recommendation, with which I concur, was that static locking (locking at both ends of the nail) be used in all femoral shaft fractures.

The patient's age is important in determining the appropriateness of locked nailing. My preference is to use locked intramedullary nails in most female patients aged 12 years and older and in most male patients aged 13 years and older. In patients below these ages, treatment is individualized, with greater use of internal fixation in younger patients with multiple trauma and additional ipsilateral injuries. One should consider flexible intramedullary nails, such as Ender nails or Rush rods, in younger patients. In the growing child, the nail must stop short of the distal femoral epiphysis. Apophyseal arrest of the trochanter has not been a problem in this population, but avascular necrosis of the femoral head has been noted in teenagers. Therefore, in younger patients a starting point for nail insertion a little farther anterior and lateral than the standard piriformis fossa starting point should be considered.

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Timing of Surgery

The timing of surgery is an important consideration. Closed reduction and intramedullary nailing with a locked nail is a personnel- and equipment-dependent operation. For a successful outcome, it is mandatory that skilled, experienced personnel be available to perform the operation and that the proper equipment be on hand. Therefore, timing may be dictated by the availability of staff and implants.

The ideal timing for intramedullary nailing is immediately after patient resuscitation. Immediate nailing appears to be even more important in the patient with multiple injuries. Bone et al[13] have clearly demonstrated a decreased incidence of adult respiratory distress syndrome with primary fixation of femoral shaft fractures compared with delayed fixation.

Preoperative Planning

Operating room planning must take place long before the first case of locked intramedullary nailing is undertaken. The surgeon must maintain up-to-date knowledge of the best available image intensifiers and must participate in the selection of this expensive device. The proper fracture table is also crucial. The best fracture table has a radiolucent perineal post, allows adequate visualization of the fracture with the patient in both the lateral and the supine position, and is small and easy for the operating staff to manage. The table should also be chosen for its usefulness for all intramedullary nailing techniques. Interlocking nails and screws in a range of appropriate sizes must be available.

In addition to the operating surgeon, another surgeon should be available to reduce the fracture. Closed reduction of the fracture is the most important and difficult part of the procedure and requires the most experience. A technician trained in the use of the C-arm image intensifier is the other critical member of the surgical team.

Traction

When nailing is immediate, a traction pin is unnecessary, since the foot can be placed in temporary traction and the femur can be nailed. In patients in whom there is concern about applying excessive traction, a femoral pin can be inserted for use during the surgical procedure. The knee is flexed to protect the sciatic nerve. In teaching institutions with changing and inexperienced staff, it may be safer in most cases to use the femoral pin with the knee flexed to avoid sciatic and peroneal injuries. If surgery is delayed, a tibial traction pin is placed, and heavy traction will be necessary to maintain the femur at length, which can be monitored on the lateral radiograph. The use of preoperative traction makes the surgical procedure much easier.

To prevent nerve palsy, it is extremely important that traction be used only during those portions of the case when it is necessary. Traction is used initially during closed reduction while the unscrubbed surgeon is determining whether the reduction can be achieved. It is released before the incision is made and is reapplied when the bulb-tipped guide has been passed. It is then relaxed and applied a final time during driving of the nail. Many surgeons apply traction and maintain it during the entire procedure. Such prolonged traction is not necessary and can be associated with an increased risk of sciatic and pudendal nerve palsies.

Patient Positioning

Lateral Positioning

Placing the patient in the lateral position on the fracture table allows much easier access to the greater trochanter than use of the supine position does and facilitates intramedullary nailing (Fig. 1). The fracture table should be equipped with a radiolucent perineal post to allow visualization of the femoral neck and shaft. Also, there must be

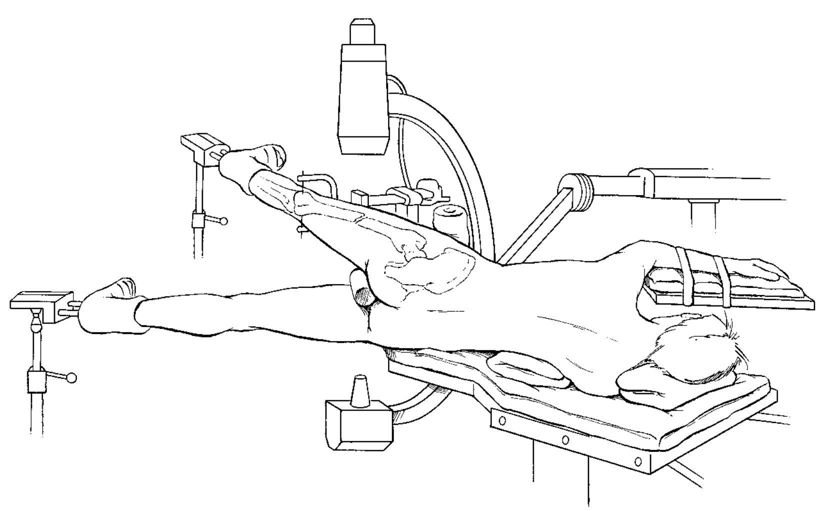

Fig. 1 Lateral positioning for intramedullary nailing.

adequate room for the image intensifier to be maneuvered proximally without bumping the upright stand supporting the table. A padded support on the anterior portion of the post is needed to cushion the iliac crest and prevent pressure on the anterolateral femoral cutaneous nerve.

The patella should be internally rotated 20 to 30 degrees toward the floor to prevent an external rotation deformity at the fracture site. Rotation is best checked by rotating the leg gently and observing the skin lines in the supracondylar region. Evaluating the fracture on the image intensifier is a poor method of judging rotation of the fracture. The potential exists for valgus sag at the fracture site, particularly in infraisthmal fractures. To prevent a valgus reduction, the unscrubbed surgeon must support the fracture both during insertion of the bulb-tipped guide and during insertion of the intramedullary nail.

Supine Positioning

Another popular method is supine positioning of the patient (Fig. 2). Surgeons and other operating room staff are generally more familiar with this technique than with lateral positioning because it is commonly used for fixation of intertrochanteric and femoral neck fractures. Unfortunately, access to the trochanter is much more difficult. It requires adduction of the leg, which creates a varus deformity in high subtrochanteric fractures. This adduction also places increased pressure on the pudendal nerve, leading to an incidence of temporary pudendal nerve palsy that can rise to as high as 10%.[14,15] A common error with supine positioning is rotation of the knee too far inward, creating internal rotation deformities. I recommend that the surgical team select a fracture table and C-arm image intensifier that are appropriate for lateral positioning, and that once they have gained sufficient experience with this positioning, they use it for most patients undergoing locked femoral nailing. An exception is the patient with multiple injuries, particularly those involving the contralateral lung, for whom the supine position is more appropriate.

Use of a Distractor

Another method of reduction is with a distractor instead of a fracture table.[16] It is difficult to place the proximal distraction pin anterior to the medullary canal. Once the device has been placed, the fracture can be distracted. The distractor may be beneficial in patients with multiple injuries, but the proponents of locked femoral nailing prefer use of the fracture table.

Determining Length

Regardless of the patient positioning used, judging the adequate length of the comminuted femur is extremely difficult.[17] Errors can be made that either leave the femur too short or overlengthen it by applying too much traction. In comminuted fractures it is best to try to select a fragment that locks into place proximally and distally for use in judging adequate length. Measuring the opposite femur to obtain a comparative length is possible, but at best this method is accurate only to within 1 cm.

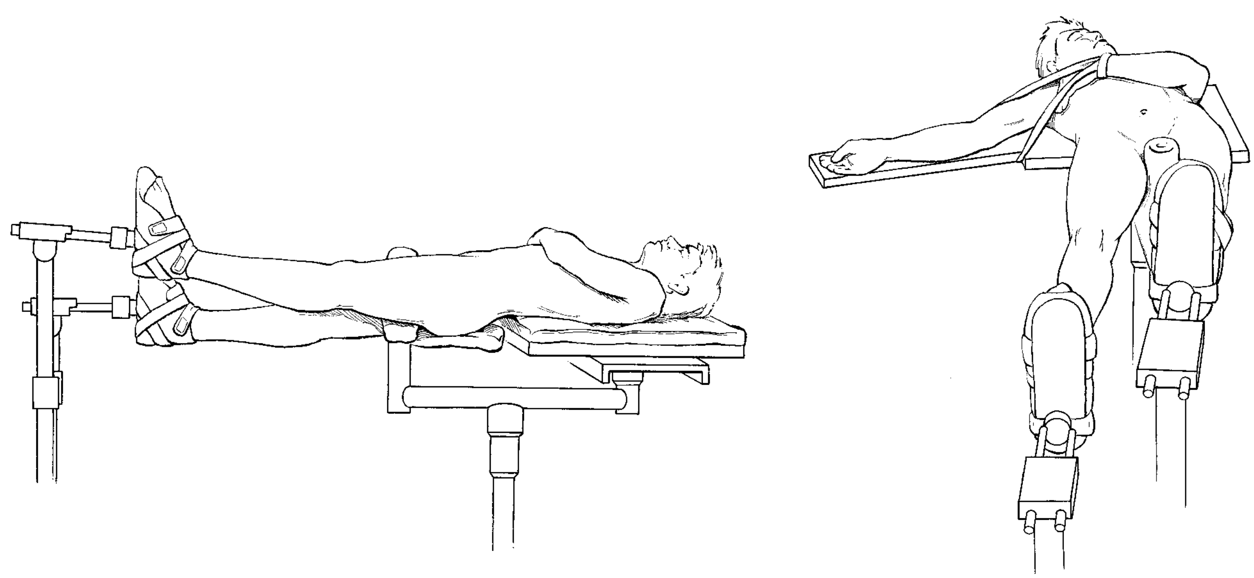

Fig. 2 Supine positioning for intramedullary nailing. Note adduction of left (operative) leg.

Closed Reduction

Closed reduction should be performed as soon as the patient is positioned on the fracture table, before preparation and draping. The unscrubbed surgeon, who should be familiar with the maneuvers necessary to reduce the fracture, may gain insight into the vectors needed for reduction by studying anteroposterior and lateral radiographs. Use of leaded gloves as well as a crutch may be helpful. Fracture tables with built-in clamps for reduction are available, but unfortunately these bulky clamps impede movement of the image intensifier and create problems during distal targeting of the interlocking screw. Once surgery has begun, a reduction rod may be placed in the proximal femur to allow manipulation of the proximal fragment. Some surgeons drape the entire thigh into the sterile field, allowing reduction of the fracture by a member of the scrubbed team. This can be facilitated by use of a sterile “reduction wrench” (Fig. 3).

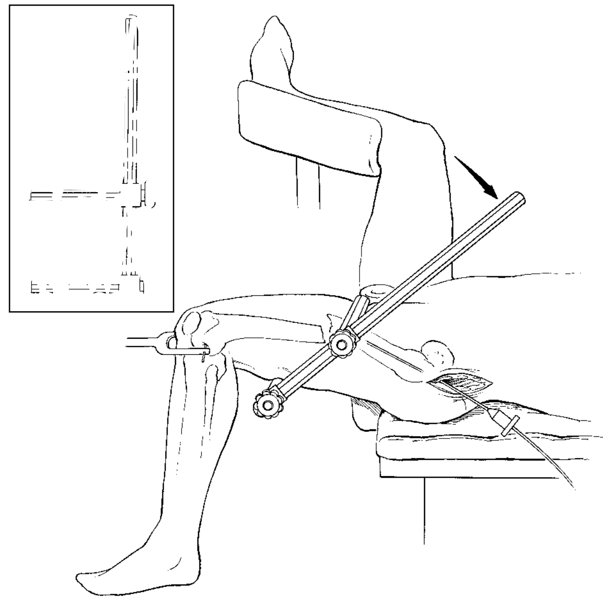

Fig. 3 Use of a sterile “reduction wrench” (**inset**) assembled from the bars used for overhead traction.

Incision

The incision should start at least 2 cm proximal to the greater trochanter and should be about 3 cm long. In obese patients it must extend even farther proximally. The dissection is carried down through the fasciae, and the trochanter is palpated. Visualization of the trochanter is not necessary; the image intensifier is used to locate the starting point for nail insertion.

Starting Point for Nail Insertion

Accomplishing the closed reduction and locating the entry portal in the femur for nail insertion are the two most important steps in the surgical procedure. A piriformis starting point appears to be the best, as the piriformis fossa tends to align with the longitudinal axis of the medullary canal.[18] Küntscher originally advised against this medial starting point because of the risk of avascular necrosis, intracapsular infection, and stress fracture of the femoral neck, but these complications have all been rare. The use of the piriformis starting point becomes even more important with nails that are more rigid than the slotted interlocking nails, because their greater rigidity increases the risk of comminution during nail insertion. Nails with an increased curvature require a slightly more posterior starting point. For second-generation (reconstruction) interlocking nails, which have screws that extend proximally into the femoral head, a starting point 5 mm anterior to the piriformis fossa allows easier placement of the screws into the femoral neck and head.

An awl is placed on the proposed starting point, and its placement is checked on both anteroposterior and lateral views with the image intensifier. Before the cortex is penetrated, the awl must be well visualized in both views and, most important, must be seen to be aligned with the medullary canal. An alternative method is to place a Steinmann pin in the appropriate starting position and to check the two planes with the image intensifier (Fig. 4) The pin is then drilled into the proximal femur, and a reamer is used over the pin to enlarge the starting point.

Reaming

Reaming of the medullary canal provides uniformity in the canal diameter and allows insertion of a larger-diameter intramedullary nail. Increasing the nail diameter dramatically augments nail strength and also permits the use of interlocking screws with a larger core diameter, which further increases strength. The use of a larger-diameter intramedullary nail also enhances alignment in midshaft fractures with minimal comminution, but is not as effective in the large canal of infraisthmal and subtrochanteric fractures.

Although reaming damages the endosteal blood supply, its restora-

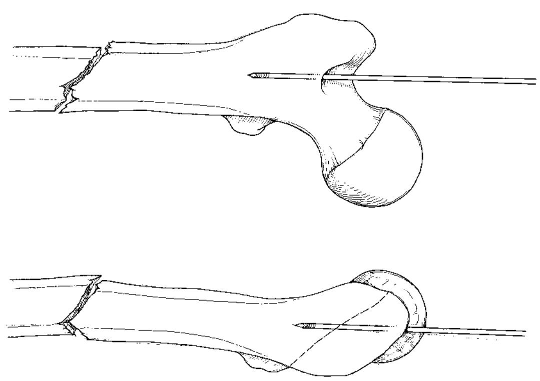

Fig. 4 The piriformis entry site should align with the medullary canal.

tion within 6 to 8 weeks has been well documented. Clinically, reaming of the femur has not been found to cause a higher infection rate or a lower union rate. Fat embolism may result from reaming, but the risk of this sequela is partially dependent on reamer design and the degree of reaming. Clinically, the risk of fat embolism is slight except in the multiply injured patient with a chest injury. In patients with such injuries, the use of an unreamed nail may be indicated, but unreamed nails have smaller diameters and unfortunately carry a higher risk of later fatigue failure than do reamed nails.

A bulb-tipped guide should always be used when reaming to allow extraction of broken reamers. The reaming should progress in 1-mm increments until cortical contact is made, after which reaming in 0.5-mm increments is advisable. Interlocking nails are stiffer than flexible Küntscher nails and frequently require overreaming in the range of 1 to 2 mm.[19] It is vitally important that the surgeon study the specific technique advocated by the manufacturer for each nail with regard to overreaming.

Jamming of Reamers and Nails

Jammed reamers can usually be freed from the femur by applying power and then quickly twisting the wrist to free the reamer. It may be necessary to use a vise grip to back the reamer out and free it from the femur. Flexible reamers should never be run in reverse, as the spiral windings can uncoil to become hopelessly tangled within the medullary canal. Inability to extract the reamer generally indicates that an infraisthmal fracture has caused a piece of bone to obstruct the intramedullary canal and block the exit of the reamer. A guide rod must then be moved down the canal to push the fragment out of the canal through the fracture site before the reamer can be removed.

If the nail fits too tightly during insertion, further reaming or a reduction in nail size is necessary. The nail should advance with each blow of the mallet; if it does not do so, it should be immediately removed before it becomes incarcerated. A large mallet is very helpful in removing incarcerated intramedullary nails. If this is not successful, it may be necessary to saw a slot into the lateral cortex of the femur, over the portion of the isthmus where the nail tip is incarcerated, to allow bone expansion.

Nail Selection

Nail Design

With the growth in popularity of interlocking nails, the number of available designs has burgeoned. In the face of union rates of 98% to 100% and infection rates of 1% with the use of these nails, it has been difficult to substantiate the clinical advantage of one design over the other.[20] Stainless steel and titanium nails appear to give equal results. Nails with a closed section (circular nails) and those with an open section (slotted nails) also provide similar results. Closed-section nails offer increased torsional rigidity,[21] but this property has no clinical significance and may lead to increased comminution at the fracture site.[22] Wall thickness has been studied in detail, and attempts have been made to increase the strength and augment the fatigue resistance of the nail. However, there is little evidence that these differences translate into a higher clinical success rate.

The only important factor related to nail design is that more rigid nails require further overreaming and perfectly placed trochanteric starting points to prevent comminution. The radius of curvature of the femoral nail varies among manufacturers. This difference is of no significance except that nails with an increased curvature require a trochanteric entry point that is a little farther posterior than the standard piriformis starting point in order to avoid shaft comminution.

There are subtle differences among nails in the proximal and distal placement of holes within the nail. A more proximal placement of the interlocking screw holes allows expansion of the indications for nailing to higher fractures, but it also causes the screw to be placed in the femoral neck, with some risk of femoral neck fatigue. A quite distal placement allows expansion of the indications to more distal fractures, but placing the screws through the wide metaphysis to reach the hole in the nail creates targeting difficulties.

Unreamed femoral nails have

relatively few indications. The increased strength and fatigue resistance of the larger-diameter reamed femoral nails have played an extremely important role in the attainment of high union rates in nailed fractures. In the femur, present indications for the smaller-diameter unreamed nails, with their increased failure rate, are confined to fractures in multiply injured patients with severe chest injuries and Gustilo grade IIIB and IIIC open fractures.[23] In these two settings, the risks of fat embolism and damage to the blood supply outweigh the risk of nail failure.

An important aspect of nail design involves the area in which the screw holes penetrate the nail. Nail failure usually occurs through the screw holes,[24] yet all bending tests comparing various products are conducted on the midshafts of the devices. Increased wall thickness of the nail in the vicinity of the hole provides increased strength.[25] Cold working of the interlocking holes has also helped increase strength and is especially important in nails with small diameters.

In summary, there is little evidence that either material or design makes a significant difference in the performance of interlocking nails. More important than either of these features is the need for the surgeon to study the technique outlined by the manufacturer for each nail and to carry it out carefully. With few exceptions, the use of reamed nails is still the standard.

Interlocking Screw Design

The design of interlocking screws is somewhat more important than nail design. Confining the threads to the distal tip of the screw has been thought to provide additional strength to the screw. Unfortunately, the weakness of the interlocking screw is at the shaft-thread junction, and thus little advantage is gained from a partially threaded screw. Also, this type of screw is less easily inserted than the fully threaded screw and is difficult to extract. Furthermore, the partially threaded screw gains purchase on only one cortex, comes loose more often, and backs out more frequently; thus, its use necessitates the placement of two screws distally. The fully threaded screw appears to have the more logical design and is easier to use.

A more important feature than the threads is the core diameter of the screw. Screw failure is a common complication of locked nails, and a larger core diameter reduces this risk. Materials such as titanium and 22-13-5 stainless steel also improve screw strength.

Static Versus Dynamic Locking

Early in the development of static locking (locking the nail at each end), there were concerns that this technique would hinder impaction and lead to an increased nonunion rate, but many clinical investigators have since demonstrated that this is not the case.[20,26] Conversely, dynamic locking (locking the nail at only one end) has been found to result in an increased rate of shortening and rotation and a higher complication rate. Dynamization (removal of the interlocking screws at one end of the nail during the healing process) was also popular early in the use of interlocking nails, but it also led to shortening and rotation at the fracture site and did not increase the union rate.[27] In light of adequate evidence of the benefits of static locking,[26] I recommend static locking of all femoral fractures from below the lesser trochanter to the supracondylar area, with dynamization reserved for those fractures that have failed to show healing at 4 to 6 months.

Distal Targeting

Accurate targeting of the distal interlocking screws in their passage into the screw holes has been the most difficult operative feature of interlocking nailing. Many attempts have been made to create proximal jigs to aid in distal targeting, but these devices have had limited value. Magnetic and light sources have also proved to be of little use. Goulet et al[28] have described the attachment of a laser beam to a C-arm image intensifier; although the device appears attractive, it has not gained widespread clinical use.[28] C-arm-mounted targeting devices have also been of limited benefit.[29] Offset-power equipment with radiolucent drill chucks has provided a slight benefit.

Freehand targeting is still the most popular method employed by surgeons experienced in this field.[30] The image intensifier is tilted and rotated until the hole appears completely round, indicating coaxial alignment. The placement of the skin incision is then determined fluoroscopically, and the fascia is split beneath it. The point of a sharp, elongated trocar with a radiolucent handle is then fluoroscopically placed at the point on the lateral cortex that coaxially aligns with the middle of the screw hole (Fig. 5). Once this point is located, the trocar or pin is driven into the lateral cortex and is then replaced with a drill bit. The drill bit can be gently tapped through the nail to the medial cortex before drilling to prevent nicking the nail with the bit and weakening it. This freehand technique has proved to be very successful and requires only slight surgical experience. It is currently the recommended method for distal placement of interlocking screws.

Number of Distal Screws

In most femoral shaft fractures, placement of a single distal screw

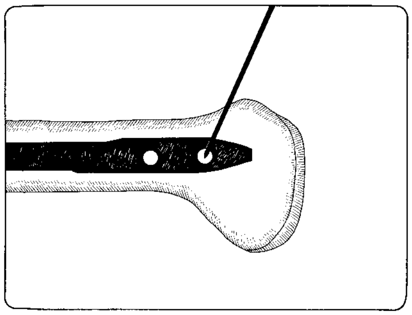

Fig. 5 The sharp trocar is brought in obliquely and aligned coaxially with the screw hole.

provides adequate fixation and decreases time spent in targeting. It appears to be unimportant whether this screw is placed in the proximal or the distal screw hole. A fully threaded screw is preferred, as a screw with distal threads tends to back out and necessitates the use of two screws.

The use of two screws is generally indicated in infraisthmal fractures to prevent rotation around the nail and flexion / extension about a single screw. Two screws are also indicated in severely comminuted femoral fractures, as well as in unreliable patients who refuse to limit weight bearing and in head-injury patients.

Postoperative Management

In patients with unstable fractures, protected weight bearing is necessary until callus formation is evident. Patients with stable fractures are allowed early weight bearing with crutch support. Each patient's weight-bearing status is progressed according to healing noted on follow-up films and clinical progress.

Quadriceps rehabilitation is generally started 1 day postoperatively. Chondromalacia is a common sequela of these injuries, and the early institution of vigorous physical therapy appears to exacerbate this condition. Therefore, the patient should begin with gentle quadriceps muscle sets, straight leg lifts, and terminal knee extensions. Progressive quadriceps muscle work should be added only as the patient improves. There is no evidence that a continuous-passive-motion machine is necessary to obtain good results.

Nail Removal

The indications for nail removal are unclear.[31,32] There are no long-term studies suggesting that removal of the nail or interlocking screws is necessary. At present, the indications for removal are symptoms of hip pain and pain over the screw heads. Screws with greater head heights tend to produce more symptoms,[12,20] as do screws in subcutaneous areas. Except in cases of delayed union and nonunion, early or late dynamization no longer appears necessary.

Open Fractures

In the treatment of open femoral fractures with interlocking nails, two important questions remain. The first is whether the nailing should be performed primarily or secondarily.[33] Little difference in the infection rate has been found between fractures nailed primarily and those nailed in a delayed manner.[34] The second question is whether the medullary canal should be reamed or left unreamed. Many reports now suggest that in open fractures caused by low-velocity gunshot wounds[35] and in Gustilo grade I, II, and IIIA open femoral fractures,[23] reamed locked intramedullary nailing is the treatment of choice. Controversy persists, however, about the treatment of Gustilo grade IIIB and IIIC open femoral fractures.[23] These fractures may be an indication for the use of unreamed interlocking nails to avoid further damage to the blood supply.

Second-Generation Interlocking Nails

Second-generation interlocking nails are used for fractures of the proximal femur and combined femoral neck-shaft fractures. These nails are available with screws of various sizes and with differing angles of placement. Use of the larger screws is unnecessary and leads to an increased rate of nail failure because these screws require larger screw holes. Screws may be placed at a 135-, a 130-, or a 125-degree angle to the femoral shaft. The normal femoral neck-shaft angle is 125 to 130 degrees, and placement of the screws at the 135-degree angle increases the difficulty of screw insertion but facilitates sliding.

Proximal targeting is much more difficult with reconstruction nails than with standard interlocking nails, and the use of a radiolucent plastic guide is helpful. The most important technique is the placement of a percutaneous Steinmann pin along the anterior surface of the femoral neck to define femoral anteversion. As the nail is driven into the bone, it must be rotated properly so that the proximal jig is parallel to the anterior pin. Correct placement of the proximal screw in the anteroposterior and lateral planes is necessary. Because the femoral neck and head project from the anterior two thirds of the femoral shaft, the starting point for nail insertion in the proximal femur is 5 mm anterior to the usual piriformis fossa starting point. This starting point places the screws in better alignment with the femoral neck and greatly facilitates proximal targeting. However, a starting point placed too far anteriorly leads to fracture of the femoral shaft and further comminution.[18]

Femoral Neck-Shaft Fractures

Femoral neck fractures are found in combination with approximately 1% of all femoral shaft fractures. As a precaution, preoperative radiographs of the hip should be taken in all patients with a femoral shaft fracture. If the proximal fragment is rotated, a femoral neck fracture may be difficult to detect on film; thus, it is helpful to examine the femoral neck under fluoroscopy during nail insertion. The majority of these femoral neck fractures are high-angle Pauwels type III fractures sustained at the time of injury, not during intramedullary nailing. It is very important to recognize the anterior location of the femoral neck relative to the femoral shaft, which makes it possible to place femoral neck pins and screws anteriorly but not posteriorly.

Femoral neck-shaft fractures can be divided into three clinical patterns: group 1, nondisplaced femoral neck fractures; group 2, missed femoral neck fractures; and group 3, displaced femoral neck fractures (Fig. 6).

Group 1: Nondisplaced Femoral Neck Fracture

This fracture combination includes a femoral shaft fracture with a nondisplaced femoral neck fracture and provides an ideal indication for second-generation locked nailing. The surgical technique involves initially placing a temporary Steinmann pin in the anterior portion of the femoral neck so that it will not obstruct the medullary canal during nail placement. The medullary canal must be reamed to a diameter 1.5 to 2 mm larger than the reconstruction nail to prevent displacement of the femoral neck fracture during insertion of the nail. Locked nailing is then carried out with a reconstruction nail, and the two interlocking screws are placed into the femoral head. After nail insertion, a third screw, which is cannulated, is added over the anterior stabilizing pin.

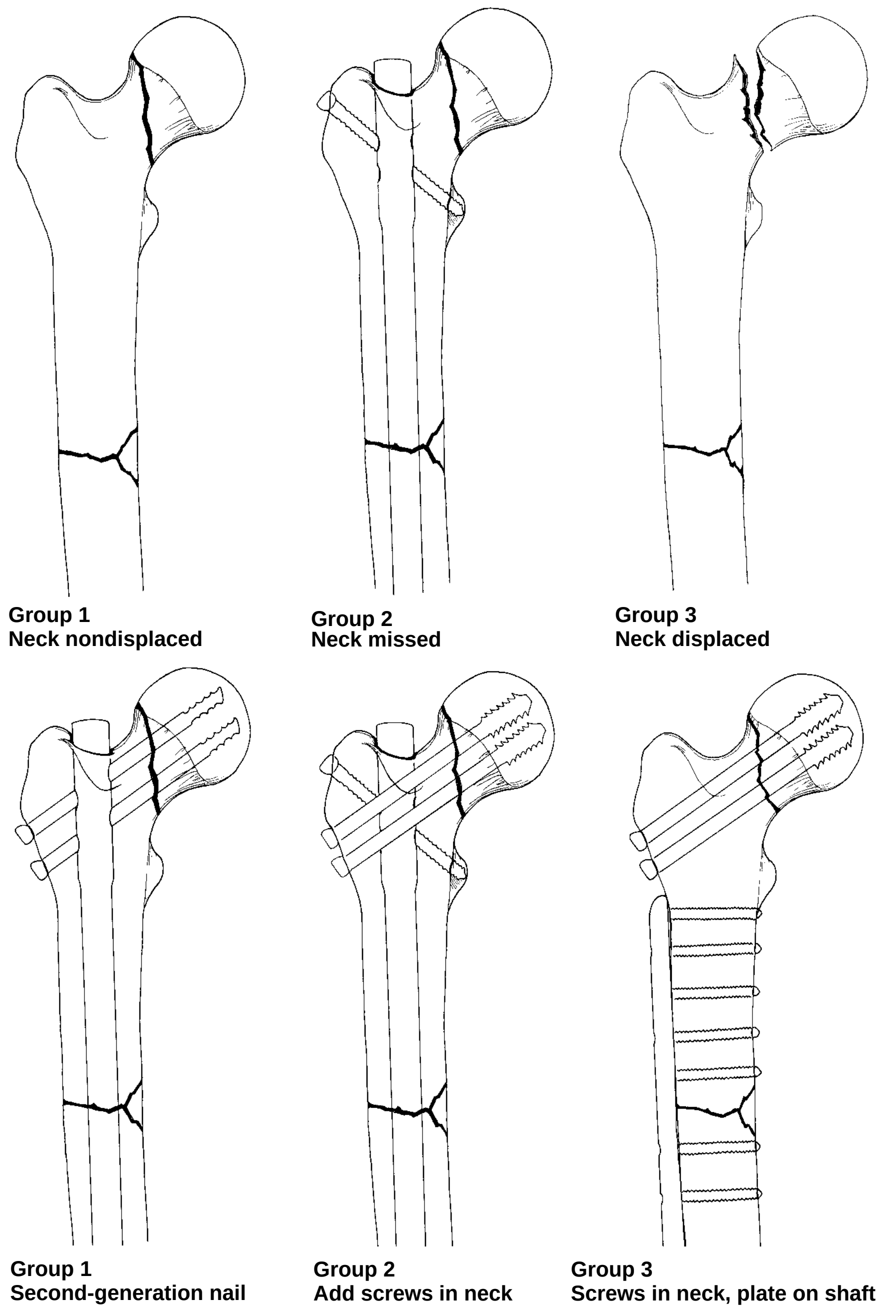

Fig. 6 Femoral neck-shaft fractures. **Top,** Classification. **Top left,** Group 1: Nondisplaced femoral neck fracture. **Top center,** Group 2: Missed femoral neck fracture. **Top right,** Group 3: Displaced femoral neck fracture. **Bottom,** Treatment. **Bottom left,** Group 1: Locked nailing is carried out with a reconstruction nail, and the two interlocking screws are placed into the femoral head. **Bottom center,** Group 2: Placement of two additional screws in the femoral neck anterior to the intramedullary nail. **Bottom right,** Group 3: Open anatomic reduction of the femoral neck and multiple-screw fixation. The femoral shaft is then managed with a plate or, in the case of a diaphyseal fracture, with a retrograde intramedullary nail.

Group 2: Missed Femoral Neck Fracture

In this group of fractures, the femoral neck fracture has been missed initially and is discovered intraoperatively or postoperatively, after the femoral shaft fracture has been nailed. The best form of treatment involves returning the patient to the operating room and placing two additional screws in the femoral neck anterior to the intramedullary nail.

Group 3: Displaced Femoral Neck Fracture

This group of fractures includes a femoral shaft fracture and a displaced neck fracture that is identified initially. The complications of nonunion and avascular necrosis that arise in femoral neck fractures are extremely difficult to manage, whereas the typical complications of femoral shaft fractures are of a lower magnitude and easier to manage. The recommended treatment for this fracture combination is an anterior capsular decompression with an open anatomic reduction of the femoral neck and multiple-screw fixation. The femoral shaft is then managed either with a plate or, in the case of a diaphyseal fracture, with a retrograde intramedullary nail.

Subtrochanteric Fractures

The availability of second-generation nails extends the benefits of locked nailing to fractures of the extreme proximal regions of the femur. There are three clinical patterns: type 1, true subtrochanteric fractures; type 2, reverse intertrochanteric fractures; and type 3, intertrochanteric-subtrochanteric fractures (Fig. 7).

Type 1: True Subtrochanteric Fractures

The lesser trochanter is intact in these fractures. True subtrochanteric fractures below the lesser trochanter can be managed with a standard (first-generation) interlocking nail.[36,37] The only patients with true subtrochanteric fractures for whom second-generation nails are indicated are those with severe osteoporosis or

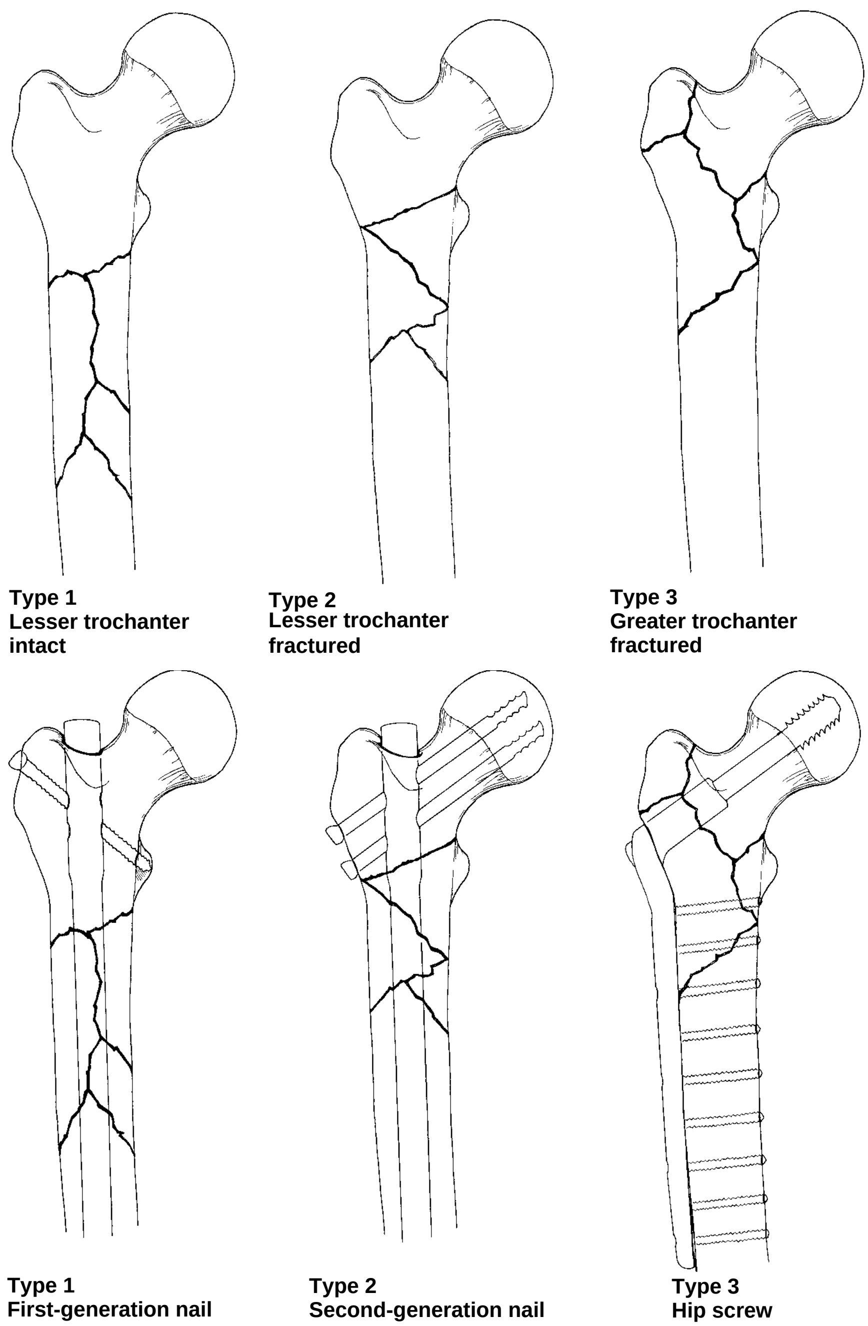

Fig. 7 Subtrochanteric fractures. **Top,** Classification. **Top left,** Type 1: True subtrochanteric fracture (lesser trochanter is intact). **Top center,** Type 2: Reverse intertrochanteric fracture (lesser trochanter is fractured, but the greater trochanter and piriformis fossa are intact). **Top right,** Type 3: Reverse intertrochanteric fracture (lesser trochanter is fractured, but the greater trochanter and piriformis fossa are intact). **Bottom,** Treatment. **Bottom left,** Type 1: Treatment is with a standard (first-generation) interlocking nail. **Bottom center,** Type 2: Treatment is with a second-generation interlocking nail, which is statically locked. **Bottom right,** Type 3: Standard treatment is with a compression hip screw.

with a metastatic lesion that may extend into the intertrochanteric area.

Type 2: Reverse Intertrochanteric Fractures

In this pattern the lesser trochanter is fractured, but the greater trochanter and piriformis fossa are still intact. These fractures provide an ideal indication for a second-generation interlocking nail, which is statically locked if there is any distal comminution.

Type 3: Intertrochanteric-Subtrochanteric Fractures

In this group the fracture extends into the greater trochanter and the piriformis fossa. Standard treatment is with a compression hip screw. Only in those cases with minimal displacement of the trochanteric fracture and extensive shaft comminution should the use of a second-generation nail be considered. Routine use of second-generation nails in these fractures has led to a high incidence of varus deformity and failure. The incidence of varus deformity is increased by supine positioning of the patient and adduction of the hip.

Summary

Closed intramedullary nailing with reamed, statically locked nails is the treatment of choice for the large majority of femoral fractures from the lesser trochanter to the supracondylar area. Closed reduction and proper location of the piriformis starting point for nail insertion are the most important aspects of the surgical technique. Nail design plays a much smaller role. Distal targeting of the interlocking screws continues to be the most difficult surgical step, and the freehand technique with a sharp trocar is commonly used. Static nailing is appropriate for nearly all femoral shaft fractures, and a single distal screw is adequate. The use of unreamed nails is appropriate only in Gustilo grade IIIB and IIIC open femoral fractures and in femoral fractures in patients with multiple injuries, particularly those involving the chest.

Second-generation interlocking nails provide an ideal treatment for combined femoral neck-shaft fractures in which the neck is nondisplaced. These nails are also indicated for pathologic fractures in the intertrochanteric and subtrochanteric regions. In subtrochanteric fractures they are best used when the lesser trochanter is fractured but the piriformis fossa is intact. A standard interlocking nail can be used in subtrochanteric fractures below the lesser trochanter. For fractures extending into the greater trochanter, the traditional compression hip screw is still the treatment of choice.

References

1. Johnson KD, Johnston DWC, Parker B: Comminuted femoral-shaft fractures: Treatment by roller traction, cerclage wires and an intramedullary nail or an interlocking intramedullary nail. *J Bone Joint Surg Am* 1984;66:1222-1235.
2. Webb LX, Gristina AG, Fowler HL: Unstable femoral shaft fractures: A comparison of interlocking nailing versus traction and casting methods. *J Orthop Trauma* 1988;2:10-12.
3. Küntscher G: Die Marknagelung von Knochenbrüchen. *Arch Klin Chir* 1940;200:443-455.
4. Winquist RA, Hansen ST Jr: Comminuted fractures of the femoral shaft treated by intramedullary nailing. *Orthop Clin North Am* 1980;11:633-648.
5. Browner BD, Cole JD: Current status of locked intramedullary nailing: A review. *J Orthop Trauma* 1987;1:183-195.
6. Küntscher G: *Practice of Intramedullary Nailing*. Springfield, Ill: Charles C Thomas Publishers, 1967.
7. Winquist RA, Hansen ST Jr, Clawson DK: Closed intramedullary nailing of femoral fractures: A report of five hundred and twenty cases. *J Bone Joint Surg Am* 1984;66:529-539.
8. Butler MS, Brumback RJ, Ellison TS, et al: Interlocking intramedullary nailing for ipsilateral fractures of the femoral shaft and distal part of the femur. *J Bone Joint Surg Am* 1991;73:1492-1502.
9. Wiss DA, Fleming CH, Matta JM, et al: Comminuted and rotationally unstable fractures of the femur treated with an interlocking nail. *Clin Orthop* 1986;212: 35-47.
10. Wiss DA, Brien WW, Stetson WB: Interlocked nailing for treatment of segmental fractures of the femur. *J Bone Joint Surg Am* 1990;72:724-728.
11. Wu CC, Shih CH: Interlocking nailing of distal femoral fractures: 28 patients followed for 1-2 years. *Acta Orthop Scand* 1991;62:342-345.
12. Brumback RJ, Reilly JP, Poka A, et al: Intramedullary nailing of femoral shaft fractures: Part I. Decision-making errors with interlocking fixation. *J Bone Joint Surg Am* 1988;70:1441-1452.
13. Bone LB, Johnson KD, Weigelt J, et al: Early versus delayed stabilization of femoral fractures: A prospective randomized study. *J Bone Joint Surg Am* 1989;71:336-340.
14. Brumback RJ, Ellison TS, Molligan H, et al: Pudendal nerve palsy complicating intramedullary nailing of the femur. *J Bone Joint Surg Am* 1992;74:1450-1455.
15. Lyon T, Koval KJ, Kummer F, et al: Pudendal nerve palsy induced by fracture table. *Orthop Rev* 1993;22:521-525.
16. McFerran MA, Johnson KD: Intramedullary nailing of acute femoral shaft fractures without a fracture table: Technique of using a femoral distractor. *J Orthop Trauma* 1992;6:271-278.
17. Wiss DA, Brumback RJ, Kyle RF, et al: Current concepts in femoral nailing. *Contemp Orthop* 1993;26:177-214.
18. Johnson KD, Tencer AF, Sherman MC: Biomechanical factors affecting fracture stability and femoral bursting in closed intramedullary nailing of femoral shaft fractures, with illustrative case presentations. *J Orthop Trauma* 1987;1:1-11.
19. Browner BD: Pitfalls, errors, and complications in the use of locking Küntscher nails. *Clin Orthop* 1986;212:192-208.
20. Cameron CD, Meek RN, Blachut PA, et al: Intramedullary nailing of the femoral shaft: A prospective, randomized study. *J Orthop Trauma* 1992;6:448-451.
21. Russell TA, Taylor JC, LaVelle DG, et al: Mechanical characterization of femoral

interlocking intramedullary nailing systems. *J Orthop Trauma* 1991;5:332-340.
22. Alho A, Moen O, Husby T, et al: Slotted versus non-slotted locked intramedullary nailing for femoral shaft fractures. *Arch Orthop Trauma Surg* 1992;111:91-95.
23. Brumback RJ, Ellison PS Jr, Poka A, et al: Intramedullary nailing of open fractures of the femoral shaft. *J Bone Joint Surg Am* 1989;71:1324-1331.
24. Bucholz RW, Ross SE, Lawrence KL: Fatigue fracture of the interlocking nail in the treatment of fractures of the distal part of the femoral shaft. *J Bone Joint Surg Am* 1987;69:1391-1399.
25. Franklin JL, Winquist RA, Benirschke SK, et al: Broken intramedullary nails. *J Bone Joint Surg Am* 1988;70:1463-1471.
26. Brumback RJ, Uwagie-Ero S, Lakatos RP, et al: Intramedullary nailing of femoral shaft fractures: Part II. Fracture-healing with static interlocking fixation. *J Bone Joint Surg Am* 1988;70:1453-1462.
27. Thoresen BO, Alho A, Ekeland A, et al: Interlocking intramedullary nailing in femoral shaft fractures: A report of forty-eight cases. *J Bone Joint Surg Am* 1985;67:1313-1320.
28. Goulet JA, Londy F, Saltzman CL, et al: Interlocking intramedullary nails: An improved method of screw placement combining image intensification and laser light. *Clin Orthop* 1992;281:199-203.
29. Kempf I, Grosse A, Beck G: Closed locked intramedullary nailing: Its application to comminuted fractures of the femur. *J Bone Joint Surg Am* 1985;67:709-720.
30. Knudsen CJM, Grobler GP, Close REW: Inserting the distal screws in a locked femoral nail. *J Bone Joint Surg Br* 1991;73:660-661.
31. Miller R, Renwick SE, DeCoster TA, et al: Removal of intramedullary rods after femoral shaft fracture. *J Orthop Trauma* 1992;6:460-463.
32. Brumback RJ, Ellison TS, Poka A, et al: Intramedullary nailing of femoral shaft fractures: Part III. Long-term effects of static interlocking fixation. *J Bone Joint Surg Am* 1992;74:106-112.
33. Chapman MW: The role of intramedullary fixation in open fractures. *Clin Orthop* 1986;212:26-34.
34. Lhowe DW, Hansen ST: Immediate nailing of open fractures of the femoral shaft. *J Bone Joint Surg Am* 1988;70:812-820.
35. Wiss DA, Brien WW, Becker V Jr: Interlocking nailing for the treatment of femoral fractures due to gunshot wounds. *J Bone Joint Surg Am* 1991;73:598-606.
36. Wiss DA, Matta JM, Sima W, et al: Subtrochanteric fractures of the femur. *Orthopedics* 1985;8:797-800.
37. Wu CC, Shih CH, Lee ZL: Subtrochanteric fractures treated with interlocking nailing. *J Trauma* 1991;31:326-333.