

Antegrade Femoral Nailing for Femoral Shaft Fracture

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4.1 Position of the Patient

IM nailing for femoral shaft fracture can be performed in supine or lateral position under general or regional anesthesia. Even though preparation time may increase, positioning the patient on the fracture table in a supine position is the most popular method because the maintenance of steady traction is the most crucial point in closed reduction, reaming process, insertion of the nail, and distal interlocking, especially in highly comminuted fracture (Figs. 4.1, 4.2, and 4.3) [1]. The biggest drawback of this position is difficulty in making proper piriformis entry (*trochanteric fossa*—see below) in some patients. The bulky

soft tissue in obese patients, narrow space between the greater trochanter and iliac crest in the small patients, and overhanging of the greater trochanter over the trochanteric fossa are the sources of trouble [2, 3]. The contralateral limb can be placed on the leg holder for free access for the image intensifier (hemi-lithotomy position); however, prolonged operation time and low diastolic pressure may evoke *compartment syndrome of the leg* [1]. In that case, the scissoring leg position is advocated. Some surgeons prefer lateral position on the fracture table, especially in subtrochanteric fracture. Flexion of the hip makes it possible to find an unobstructed route to the entry site without difficulties [1, 4].

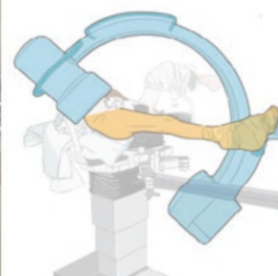
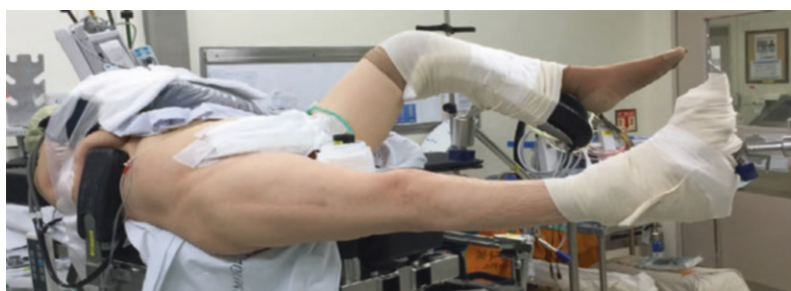


Fig. 4.1 Preparation of patient on the fracture table in a supine position. Adduction of the injured limb is necessary to approach the entry point (trochanteric fossa).

Abduction/flexion of the contralateral limb provides the free space for fluoroscopy

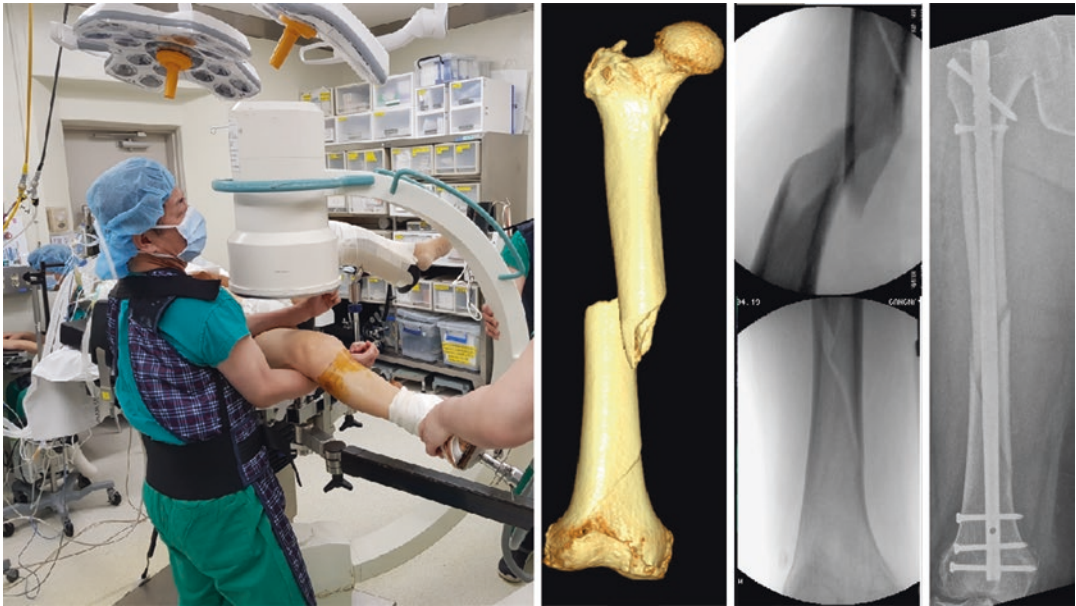


Fig. 4.2 Closed reduction of a spiral fracture before positioning the patient on the fracture table. After placing the patient on the fracture table, check out the fracture site with fluoroscopy. The entire femur must be visualized without obstruction in AP and lateral views. When the leg is fixed on the fracture table, it is challenging to reduce a spiral fracture during the IM nailing process. If the distal

fragment is displaced into the femur's other side, the leg and footplate are released from the fracture table. Then, the injured limb is mobilized in circumduction (counterclockwise rotation of leg, in this case, left figure) for reduction. After closed reduction, refix the footplate to the fracture table and confirm the alignment

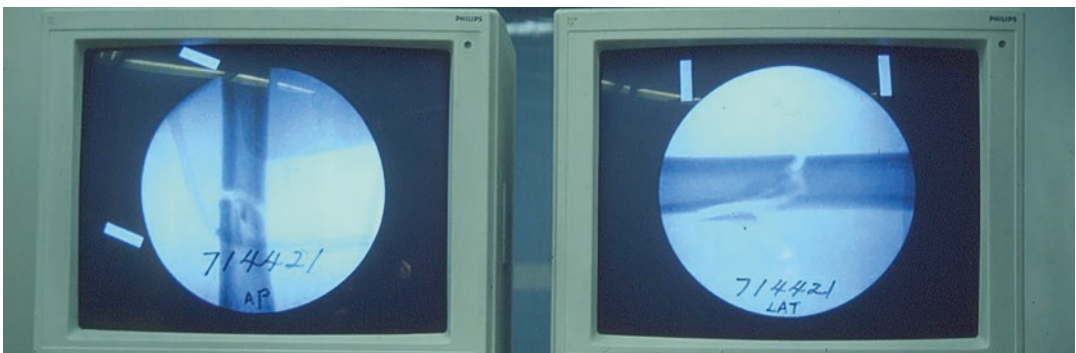


Fig. 4.3 Final adjustment of leg position before incision. Align the injured limb with reasonable traction force to align the fractured femur in AP and lateral view before starting IM nailing. If you find some differences in cortical thickness between proximal and distal fragments, think about the malrotation and correct it. It dramatically facilitates IM nailing when you get a proper alignment

because it guarantees free passage of a ball-tip guidewire, reamers, and a nail. Slight over-traction is acceptable because traction can be released once the nail enters the medullary canal of the distal fragment for a few centimeters. The gap would disappear. If not, counter-tract the distal thigh and knee while the nail advances

4.2 Entry Point (for the Straight Femoral Nail)

Defining the appropriate entry point is a problematic issue in antegrade femoral nailing. Nowadays, most surgeons agree that the ideal entry site is a proximal exit of the bisecting line of the medullary cavity of the femur. Küntscher inserted the straight open section cloverleaf nail from the tip of the greater trochanter, namely the *piriformis fossa*. The piriform fossa is an insertion site of the piriform tendon and represents a slight, shallow depression located on the tip of the greater trochanter. The tip of the greater trochanter was used as an entry point to avoid possible violation of blood supply to the femoral head and septic arthritis following intracapsular infection at that time [5–8]. However, over one-half of the cases show that insertion of the straight femoral nail from the tip of the greater trochanter (GT, X in the Fig. 4.4) may result in lateral insertion. Lateral insertion of the stiff straight femoral nail is detrimental in some cases (Fig. 4.4a and b), resulting in varus tilting of the proximal frag-

ment and bursting of the medial cortex of the proximal fragment and fracture of the greater trochanter (Fig. 4.5) [2, 3].

As a result, the surgeons sought more medial entry sites, namely trochanteric fossa, to avoid lateral insertion in these cases (Fig. 4.4a and b). The proximal exit of a bisecting line of the medullary canal passes around the *trochanteric fossa*. The trochanteric fossa is a deep depression on the inner surface of the greater trochanter and represents the insertion of the obturator externus muscle. Contrary to the concern during the early development of IM nailing, the use of trochanteric fossa as an entry point in *adult* femoral nailing does not violate the circulation of the femoral head. *These days, people agree that the trochanteric fossa is an appropriate entry point for antegrade femoral nails in adults.* Many surgeons have shifted the entry site from the tip of the greater trochanter (piriformis fossa) to the trochanteric fossa for mechanical reasons. They, however, have kept using the term “piriform entry” incorrectly in many published articles (Fig. 4.6) [2, 3, 6].

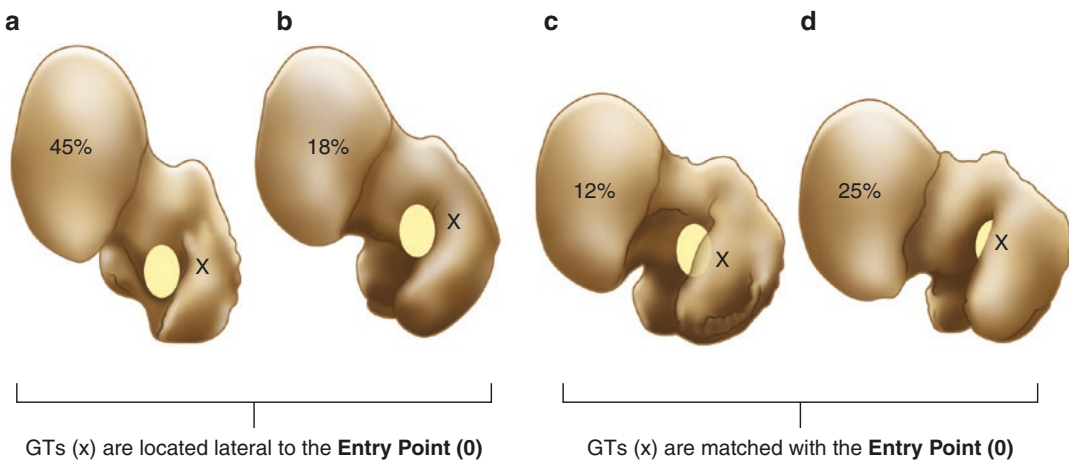


Fig. 4.4 Photographs showing the overhang of the greater trochanter at the site of insertion. From a cranial view, it was graded into four groups: group (a) specimens offer full access to the entry point (white circle); group (b) specimens are defined by a laterally projecting spine; group (c) specimens have a partially covered entry point;

and group (d) specimens have a completely covered entry point. Relationship between the tip of the greater trochanter (X) and trochanteric fossa (white circle). A mismatch is shown in Group (a) and (b). Insertion of the straight nail from the tip of the greater trochanter may result in lateral insertion in these groups



Fig. 4.5 Lateral insertion of the straight femoral nail resulting in varus tilting of the proximal fragment and the fracture of the medial cortex

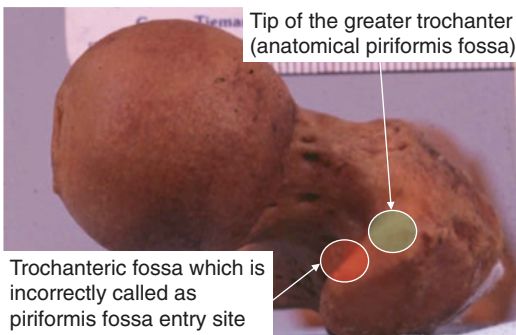


Fig. 4.6 Relationship between piriformis fossa and trochanteric fossa. Many surgeons have shifted the entry site from the tip of the greater trochanter (anatomical piriformis fossa; green circle) to the trochanteric fossa for mechanical reasons. The trochanteric fossa is a deep depression on the inner surface of the greater trochanter and represents the insertion of the obturator externus muscle (red circle). In many published articles, people kept using the term “piriform entry” incorrectly to describe the entry point (trochanteric fossa)

The chief problem in using trochanteric fossa as the entry point is hiding of entry point by an overhang of the greater trochanter in some cases (Fig. 4.7). External rotation of the proximal fragment, especially in subtrochanteric fracture, aggravates the situation. The greater trochanter starting femoral nails have been developed and released in the twenty-first century to overcome these problems. *Preoperative planning is important in selecting the proper entry point for the intended use of the femoral nail; piriformis fossa* (it is a misnomer; trochanteric fossa is correct) vs. *greater trochanter* starting femoral nail.

Since the tip of the greater trochanter is easily palpable through the surgical incision, I would focus on preparing the entry point on the trochanteric fossa in this chapter. If the patient is prepared on the fracture table in a supine position, adduction of the injured limb and deviation

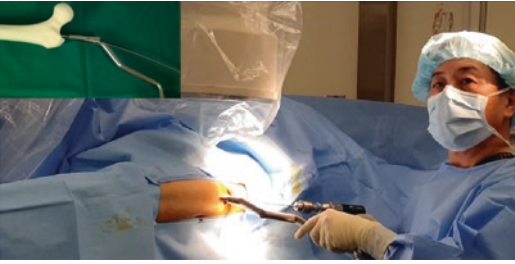


Fig. 4.7 Technique to solve the problem of an overhang of the greater trochanter over the trochanteric fossa. The use of an outer sheath of separable awl or similar equipment (inlet) makes it possible to bend the end of the guide pin outward to face toward the center of the medullary cavity. This technique is handy in the cases of an overhang of the greater trochanter (Group C and D in Fig. 4.4), obese patients, and small patients whose working space between the greater trochanter and the iliac crest is narrow. The amount of bending is controllable while watching the fluoroscopic images. The best entry point is where the imaginary bisecting line of the medullary canal exits in both hip AP and lateral images. It is usually around the “trochanteric fossa,” which is frequently referred to as “piriformis entry” incorrectly

of the trunk to the intact side is necessary. However, excessive adduction tightens the lateral fascia and iliotibial band, making it difficult to palpate the deeply seated trochanteric fossa [6]. Under the guidance of a fluoroscope, the tip of the guide pin is inserted into the medial aspect of the greater trochanter. If the tip of the guide pin is located in the superior part of basi-cervical region in the hip AP view, it is located too anterior and vice versa. In some cases, the trochanteric fossa is visible in the fluoroscopic image (Fig. 4.8).

Suppose external rotation of the proximal fragment hinders the proper evaluation of the anatomy. In that case, you may insert the long curved hemostatic forceps at the level of lesser trochanter through a small stab wound on the posterolateral aspect of the thigh. Elevation of the handle of hemostatic forceps rotates the proximal fragment internally and visualizes the greater trochanter’s medial aspect clearly. It was a great discovery

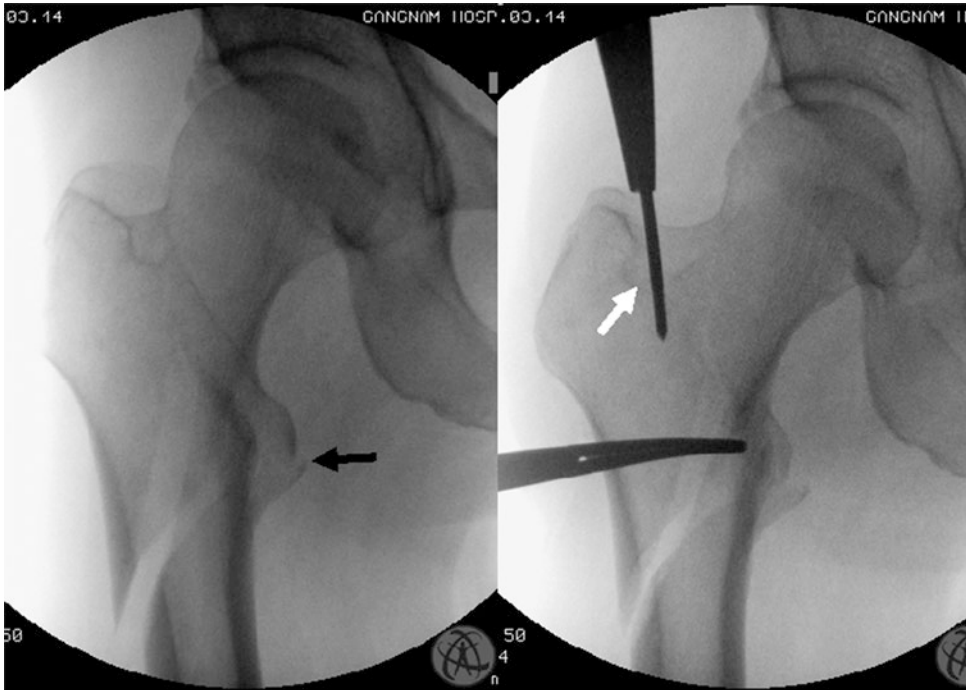


Fig. 4.8 The effects of internal rotation of the proximal fragment-I. Prominent lesser trochanter (black arrow) indicates external rotation of the proximal fragment. It shortens the femoral neck in the hip AP image and hides the trochanteric fossa by the posterior lip (intertrochanteric crest) of the greater trochanter. Internal rotation of the proximal

fragment solves all the problems described in the previous sentence. The long femoral neck helps get a better orientation of the anatomic structures. An unobstructed clear view of the medial aspect of the greater trochanter opens the route to the trochanteric fossa (white arrow) for the guide pin. It facilitates the preparation of the entry point

improving visualization of the medial aspect of the greater trochanter, as shown in the following figures (Fig. 4.8) [8]. With the help of a curved cannulated awl or similar equipment, we can bend the tip of the guidewire smoothly to advance it into the center of the medullary canal (Fig. 4.7). Otherwise, it hits the medial cortex of the proximal femur. The unexpected beneficial effect of internal rotation of the proximal fragment is a simultaneous correction of associated flexion and abduction deformity of the proximal fragment (Figs. 4.9 and 4.10).

After advancing a guidewire for 5–10 cm, check out the lateral image of whether the guidewire is located in the center of the medullary canal. After final confirmation of the guide pin position, entry site reaming can be performed with a trochanteric reamer. Some surgeons use a cannulated curved awl to enlarge the entry site to pass a ball-tip guide pin. It is crucial to *avoid the trochanter fossa* in the juvenile patient to prevent avascular necrosis of the femoral head after antegrade femoral nailing (Figs. 4.11 and 4.12).

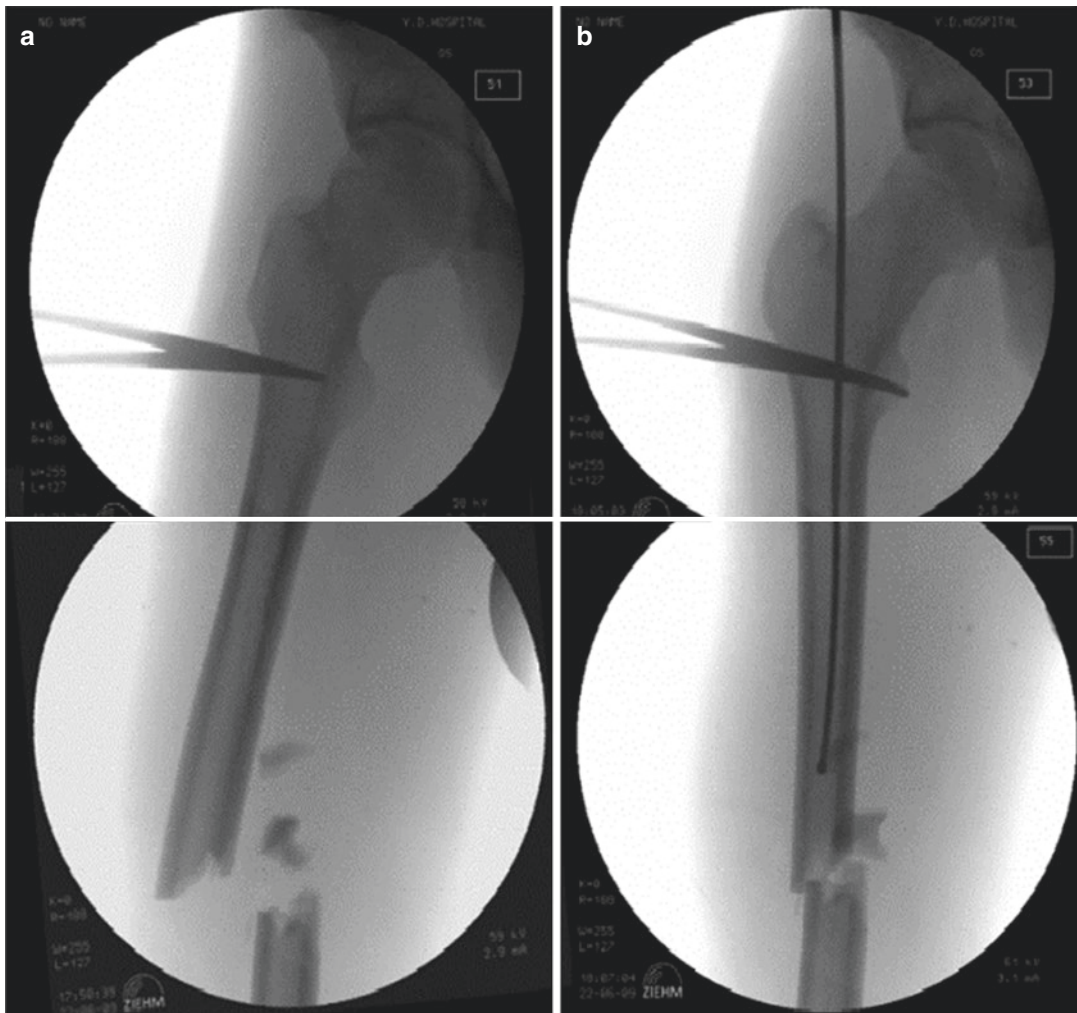


Fig. 4.9 The effects of internal rotation of the proximal fragment-II. Correction of external rotation by insertion and elevation of the curved hemostatic forceps (internal rotation) provides a clear view of the proximal femur, facilitating the preparation of the entry point. In addition,

it simultaneously corrects abduction and flexion deformity of the proximal fragment and aligns the fracture fragments for easy passage of the ball-tip guidewire [9]. (a) external rotation of the proximal fragment. (b) internal rotation using the curved long hemostatic forceps

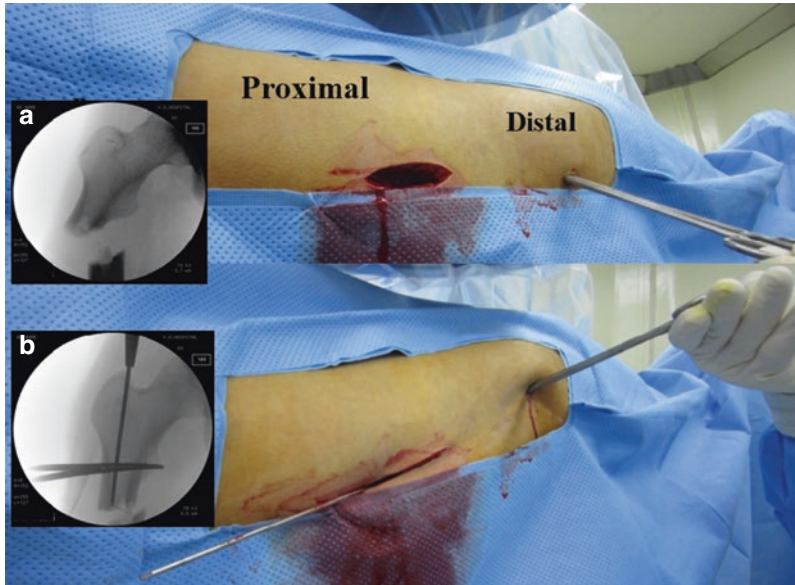


Fig. 4.10 The shorter the proximal fragment, the greater the displacement. IM nailing for subtrochanteric or proximal femoral shaft fracture is difficult due to severe flexion, abduction, and external deformity of the short proximal fragment (a) The shorter the proximal fragment, the greater the displacement. In general, a stab wound for insertion of the long curve hemostatic forceps is made at the lesser trochanter level. It is usually made at the posterolateral thigh (posterior margin of the femur by palpa-

tion). The arms of long curved hemostatic forceps are rolled over the lateral aspect of the femur and the anterior surface. Once it reaches the medial edge of the femur, internal rotation of the proximal femur is performed by elevating the forceps handles. It brings a clear hip AP view. It significantly facilitates the preparation of the entry site (b) When correction of the initial deformity is insufficient, the second forceps can be introduced and repeated [9]

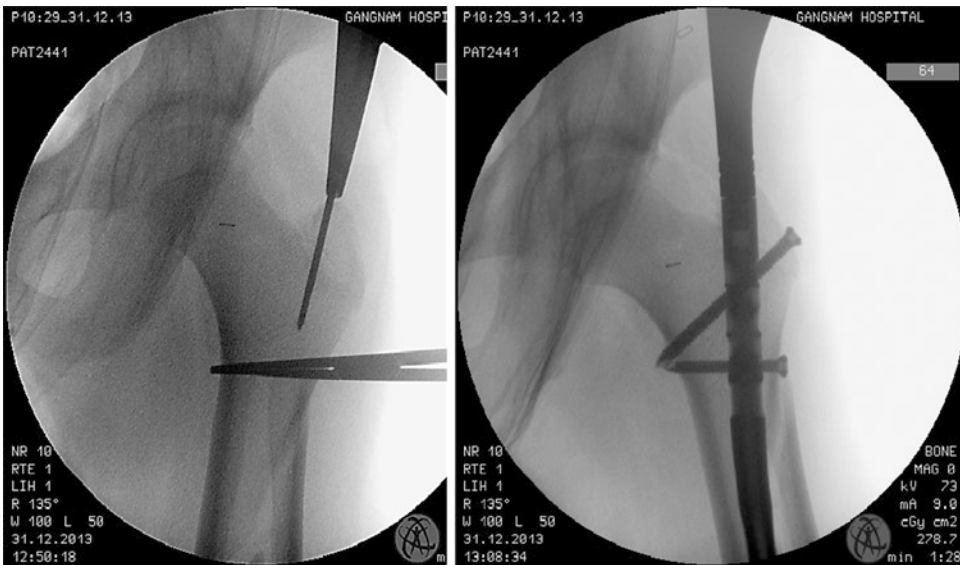


Fig. 4.11 Greater trochanter entry point for juvenile patient. A 14-year-old boy sustained a pedestrian injury. The tip of the greater trochanter was used for nail entry (ZNN greater trochanter starting antegrade femoral nail)

to protect the circulation to the femoral head. It is crucial to *avoid the trochanter fossa* in the juvenile patient to prevent avascular necrosis of the femoral head after antegrade femoral nailing

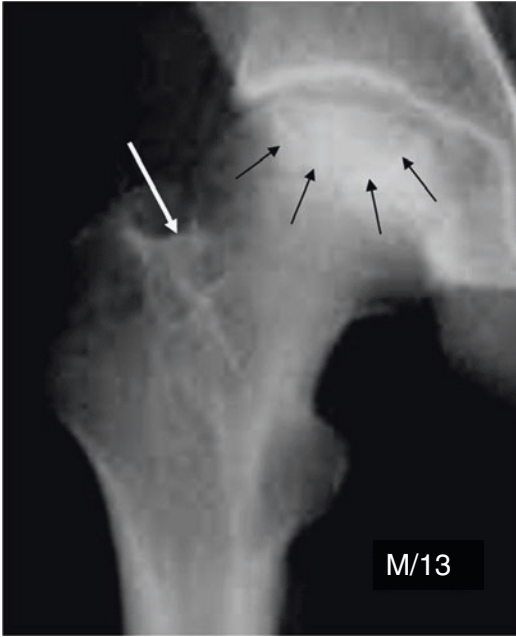


Fig. 4.12 Avascular necrosis of the femoral head after IM nailing in a 13-year-old boy. The nail entry is medial to the tip of the greater trochanter (white arrow) and avascular necrosis of the femoral head has developed at the weight-bearing area (small back arrows). This complication must be avoided

Summary of Entry Point (Fig. 4.13)

Prominent lesser trochanter (black arrow) shown in the hip AP images indicates the external rotation of the proximal fragment. Internal rotation of the proximal fragment provides clear anatomic landmarks in the superior border of the femur, such as the superior cortex of the femoral neck, trochanteric fossa (white arrow), and medial slope of the greater trochanter. Those structures are essential in selecting an appropriate entry point. The position of the guide pin must be checked in the lateral view and the AP view. After insertion of the femoral nail and interlocking screws, confirmation of the femoral neck in the internal rotation is again essential to check the possibility of an occult ipsilateral femoral neck fracture. The prophylactic femoral head and neck screw is inserted due to the “positive CT capsular sign” (see Chap. 5) in this case. Correct entry point leads to successful IM nailing. *So, do not hesitate to spend valuable time making a correct entry site even though you might experience a few unsuccessful attempts.*

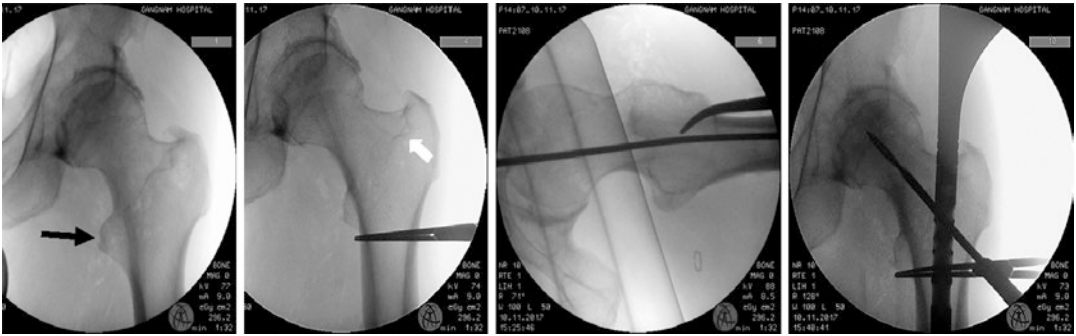


Fig. 4.13 Correct sequences for entry point preparation

4.3 Reduction Technique

Fracture reduction for IM nailing means restoration of the anatomic alignment of the femur. It consists with:

- Restoration of length,
- Reduction of the fragments for passage of a ball-tip guidewire,
- Correction of angulation and displacement during nail insertion,
- Prevention of malrotation.

(a) *Restoration of length* is usually achieved by longitudinal traction of the injured limb on the fracture table. Some surgeons performed femoral nailing in a supine position on the ordinary table.

There is no problem with the cases with simple or less comminuted femoral shaft fractures. However, the fatigue limit of the assistant may hinder the precise positioning of a nail, blocking screws, and interlocking procedure in highly comminuted fractures. A simple length measure of the intact side femur from the greater trochanter to the upper pole of the patella is helpful before positioning the patient on the fracture table. In the case of both femora fractures, try to perform the less comminuted side first and use the nail of the same length on the more comminuted side [1, 10, 11]. I prefer a combination technique with an external fixator (two-staged operation) in open fracture with loss of large segment (Fig. 4.14).

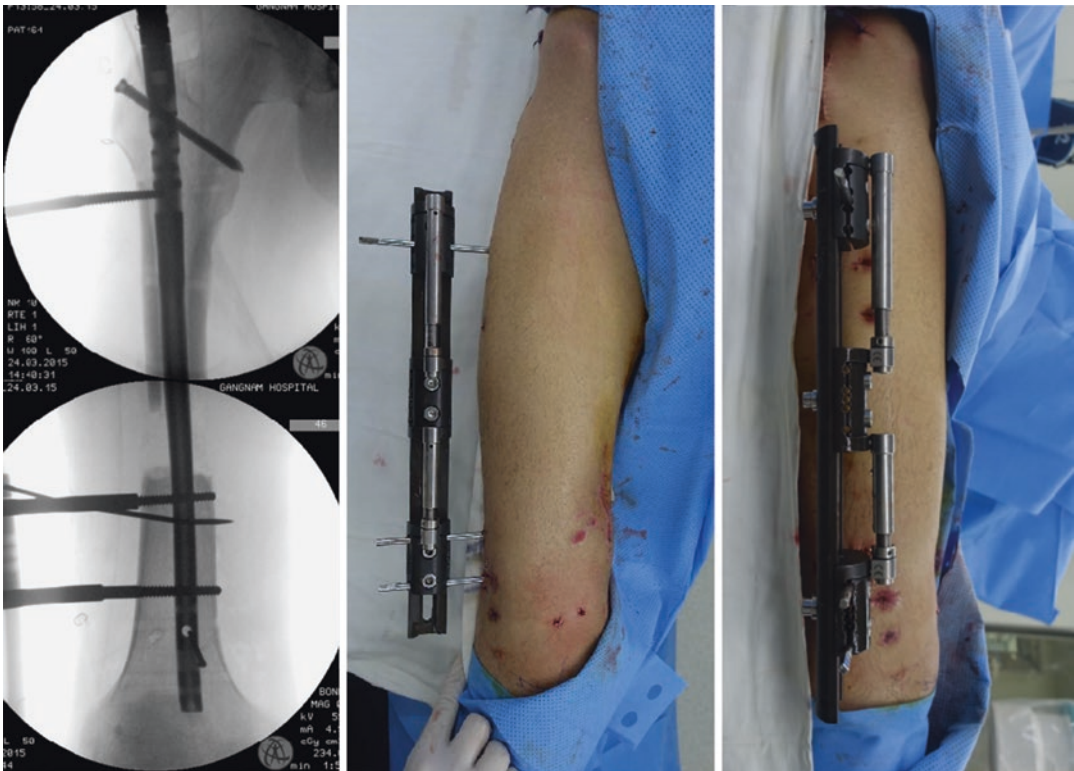


Fig. 4.14 Combination of IM nail and external fixator (EF) for lengthening in the open femoral fracture. The margin of error is tiny if you plan femoral lengthening using a Monorail type EF after femoral nailing. So precise fracture alignment, nail position (use of Poller screw to get proper alignment—lateral Steinman pin in the lower left fluoroscopic image), and correct EF pin placement are

mandatory. EF pins must be perpendicular to the long axis of the femur. The proximal EF pin is through the dynamic hole of the nail, and distal EF pins are located posterior to the nail in this case. Careful preoperative planning is necessary for complicated cases. Make sure that fluoroscopy can visualize the entire length of the femur without obstruction before the surgery. For details, see Chap. 7

(b) *Reduction of the fragments for passage of a ball-tip guidewire.*

One of the most challenging deformities during the reduction of femoral shaft fracture is sagging at the fracture. This is caused by an inherent anterolateral bowing of the femur, the tension of the gastrocnemius muscle due to traction in knee extension, and the weight of the thigh. You will fail to pass the ball-tip guidewire if you attempt to correct it with more traction force. The best way is (Figs. 4.15 and 4.16):

- (1) Ream the proximal fragment only until 12 mm,
- (2) Insert the reduction finger (instrument) to the end of the proximal fragment,
- (3) Face the fingertip toward the displaced distal fragment,

- (4) Aggravate the deformity temporarily and manipulate the reduction finger so that the fingertip can catch the entry of the medullary in the distal fragment,
- (5) Turn the reduction finger 90°–180° to correct the sagging deformity,
- (6) Advance the reduction finger into the distal medullary canal for a few centimeters,
- (7) Advance the ball-tip guidewire to the distal fragment.

A more displaced fracture is usually hard to get closed reduce in the segmental fracture. The introduction of a curved hemostatic forceps through a stab wound into the fracture site again helps reduce the fracture by leverage technique (Fig. 4.17). When displacement occurs in the long spiral fracture in the proximal or distal metaphysis,

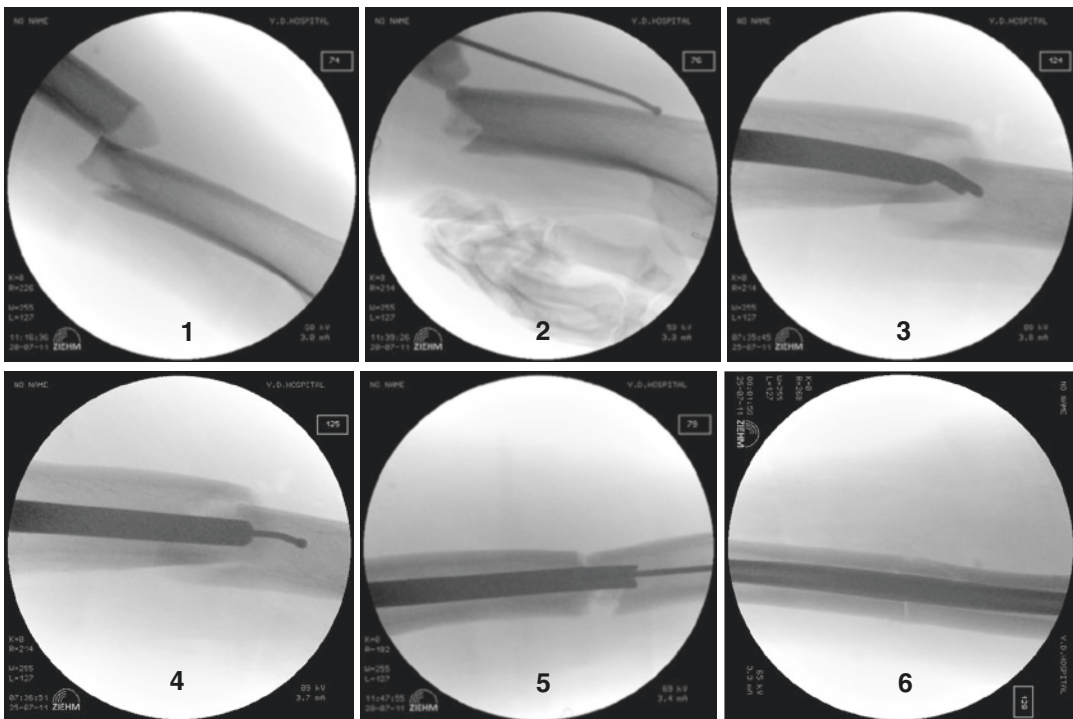


Fig. 4.15 Sagging is an annoying deformity during IM nailing. Simple external pressure or support usually fails (1, 2). You may try the crutch and band techniques when available. My favorite method is the manipulation of the reduction finger. A hard curved fingertip is advanced while searching the entry of the distal medullary canal (3).

Once it enters the canal, rotation of the reduction finger reduces the fracture displacement (4–6). I used to manipulate a reduction rod or a reduction finger during IM nailing, but I think a reduction finger is a more convenient way of helping pass a ball-tip guidewire to the distal fragment. Joystick maneuver is another option

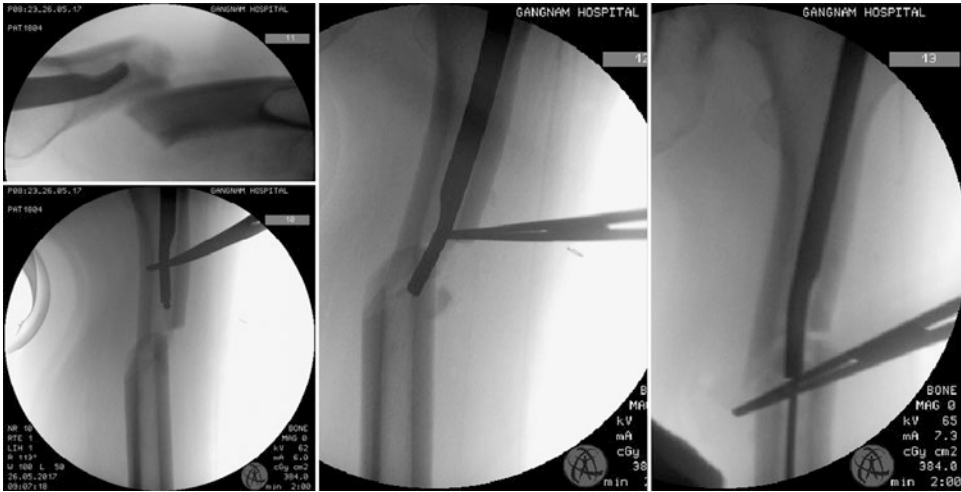


Fig. 4.16 Another demonstration of a reduction finger. Flexion deformity of the proximal fragment was controlled by the long hemostatic forceps. After reaming the proximal fragment, a cannulated reduction finger is inserted into the medullary canal with a ball-tip guide-

wire. The curved fingertip should face the center of the distal fragment (middle column). It facilitates catching the opening of the distal medullary canal. Serpentine movement of the reduction fingertip enables us to pass it through the medullary canal and reduce the fracture



Fig. 4.17 A segmental fracture requires the patience and skill of the surgeon. Flexion, abduction, and external rotation deformity of the short proximal fragment are corrected using the long curved hemostatic forceps [serial images on the upper column]. Distal one-third fracture shows a huge displacement. Use of reduction finger is not appropriate due to long lever arm in the distal fracture. Introduction of a curved hemostatic forceps through a stab wound into the

fracture site again helps reduction of the fracture by leverage technique [scooping of the far fragment (middle fragment) using the forceps arms while the body of the forceps abuts the near fragment (distal fragment) working as a hinge (thick white arrow indicates reduction maneuver)]. Once the shortening and displacement were overcome, the reduction would be achieved with a clunk (thin white arrow) [serial images on the lower column]

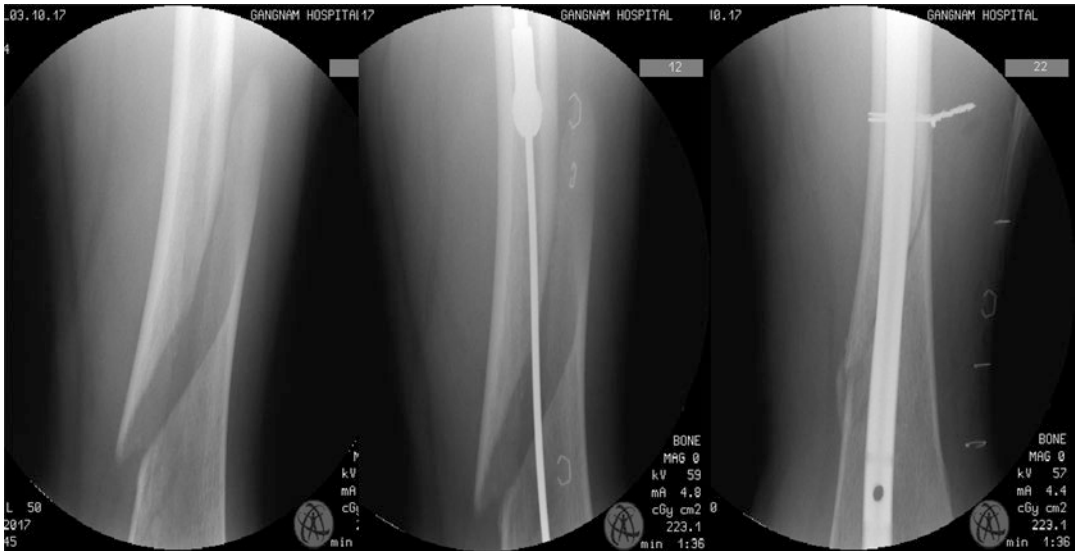


Fig. 4.18 Long spiral fracture at the distal one-third of the femur is a good indication of wiring. Since the fracture usually occurs in the old ladies, it is difficult to be reduced by Poller screw alone. Application of Poller screw without initial reduction may cause second fracture (split of the distal fragment) due to osteoporosis. The wiring tech-

nique effectively reduces the fracture gap and augments the fixation with the interlocking nail. As there have been reports of entrapment of a femoral artery and subsequent above-knee amputation after wiring, it must be performed with special care. Wire passer must be touched with the femur through the course and procedure [12]

wiring the fracture after the open or semi-open technique is preferable to leaving a large gap. Cerclage wiring of the displaced fracture with minimal soft tissue handling gets popular these days. It helps reduce the long spiral fracture or large butterfly fragment and enhances stability during and after nailing (Figs. 4.18, 4.19, and 4.20).

(c) *Correction of angulation and displacement* is less problematic in the shaft area than in the infra-isthmic area because occupancy of the medullary canal with the largest nail possible after adequate reaming automatically realigns the diaphysis unless the isthmic area is highly comminuted. However, in the distal metaphyseal area, the medullary canal widens like the bell of a trumpet, negating the effect of

the IM nail. Use of Poller screw or blocking screw is highly advocated in this area when angulation of the distal fragment hinders the restoration of anatomical alignment. Advantages of Poller screw are enhancement of distal fixation by preventing recurrence of angular displacement as well as correction of angular malalignment during nail insertion (Figs. 4.21 and 4.22) [1, 11, 13].

Displacement frequently occurs in the distal femoral fracture. The use of various bone clamps is necessary to get the reduction. Ugly displacement at the supracondylar area is challenging to be reduced by ordinary methods. A Schanz pin at the lateral femoral condyle for manipulation, a Poller screw on the nail's lateral side, and a collinear clamp are useful tools for closed reduction (Fig. 4.23).

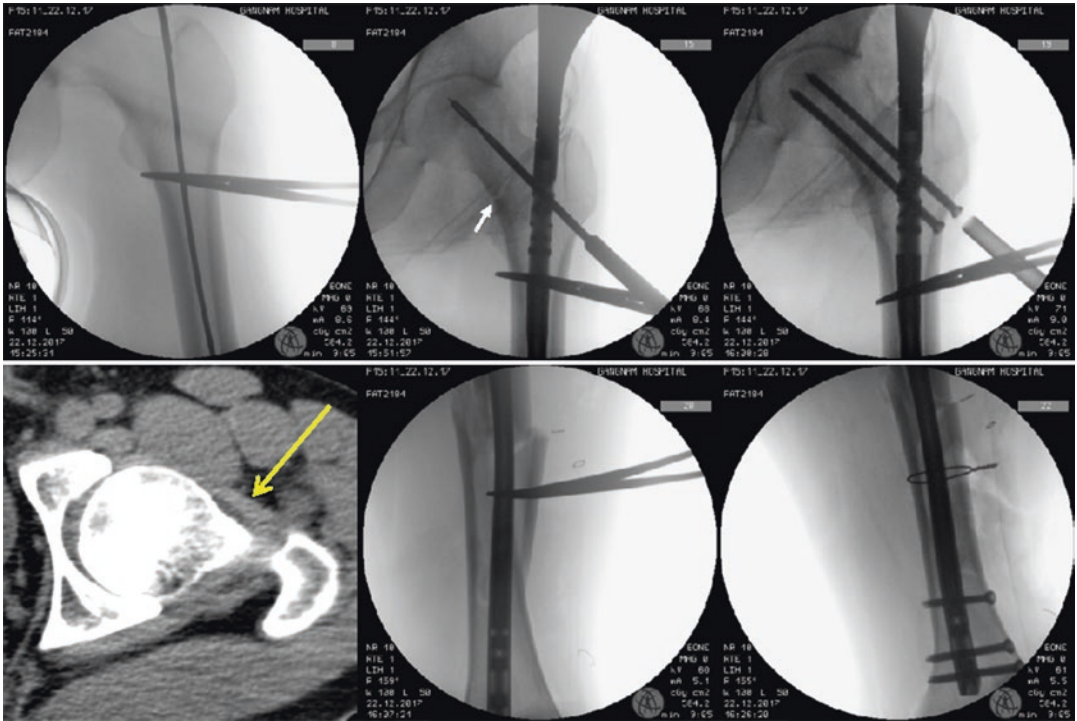


Fig. 4.19 Wiring of the comminuted fragment needs small incision usually at the lateral aspect of thigh. Initial valgus malalignment was corrected after wiring of the comminuted fragment. In this case, undisplaced silent ipsilateral femoral neck fracture was displaced during the

nailing (small white arrow). Therefore, reconstruction type nailing was performed. Preoperative hip axial CT images revealed capsular sign that implicated undisplaced femoral neck fracture (see Chap. 5)

(d) *Rotational alignment.* Once length and correction of the angular deformity are achieved, it is time to think of the rotational status of the nailed femur. Anteversion of the femur is different from person to person (Fig. 4.24). In general, restoration of rotational alignment between 0° and 15° is advocated unless the angle of anteversion is measured by computed tomography in the contralateral femur beforehand. Malrotation over 15° is not recommended. The lesser tro-

chanteric sign is extremely valuable, but the surgeons frequently focus on IM nailing procedure itself and omit to get the AP image of the contralateral hip with the patella forward beforehand (Figs. 4.25 and 4.26) [11, 14–17]. Taking advantage of an inherent anteversion of the intramedullary nail is a useful tip to avoid the malrotation in the highly comminuted femur fractures, which includes fracture of the lesser trochanter (Fig. 4.27) (Table 4.1).

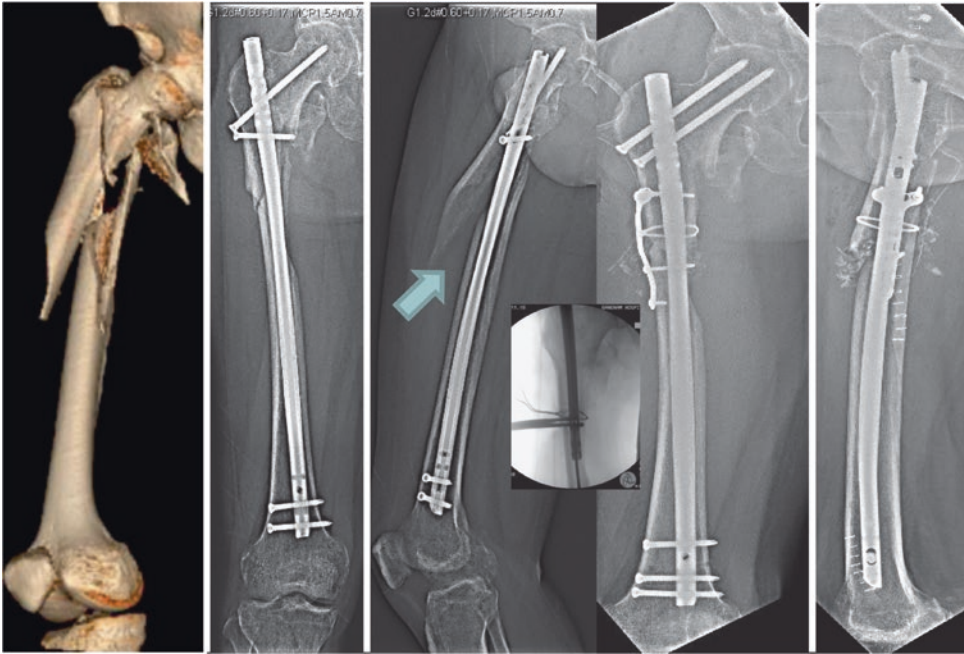


Fig. 4.20 A 35-year-old male patient sustained a motorcycle accident. He underwent closed reduction and internal fixation with a reconstruction nail for the trochanteric fracture with serious subtrochanteric extension. However, the surgeon failed to get a proper reduction (arrow). Six months after the initial surgery, he was transferred to our hospital for revision. Due to a long-standing malalignment, open reduction using a bone clamp and cerclage wiring was necessary to maintain the reduction during exchange nailing. Plate augmentation and autoiliac bone graft were performed due to the gap at the fracture site.

Due to the fracture of the lesser trochanter, the inherent anteversion of the ZNN femoral nail (15°) was used to get proper rotational alignment (see below). Proper alignment was achieved and bone healing was progressing 2 months postoperatively. Flexion deformity of the proximal fragment was corrected as shown in the lateral view of the femur after the operation (right). A bone clamp and cerclage wiring were applied to reduce the gap during IM nailing. Augmentative plating and autoiliac bone graft were performed due to a defect on the medial side

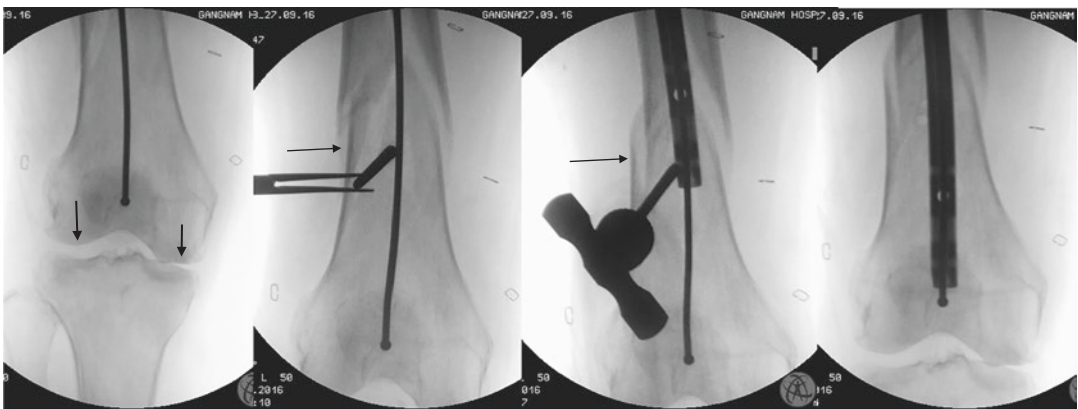


Fig. 4.21 Poller screw (pin) to realign the distal fragment. Although a longitudinal alignment looks good after reduction, flattening of the medial femoral condyle and valgus of the femoral articular surface are noted (arrows in the left image). A Steinmann pin is inserted just lateral to the ball-tip guidewire to induce lateral displacement of the

distal femur and decrease the valgus alignment (compare each arrow in the two middle fluoroscopic images). The lateral cortex of the distal fragment moves laterally when the nail abuts the Poller pin. (See Chap. 8 for the use of a

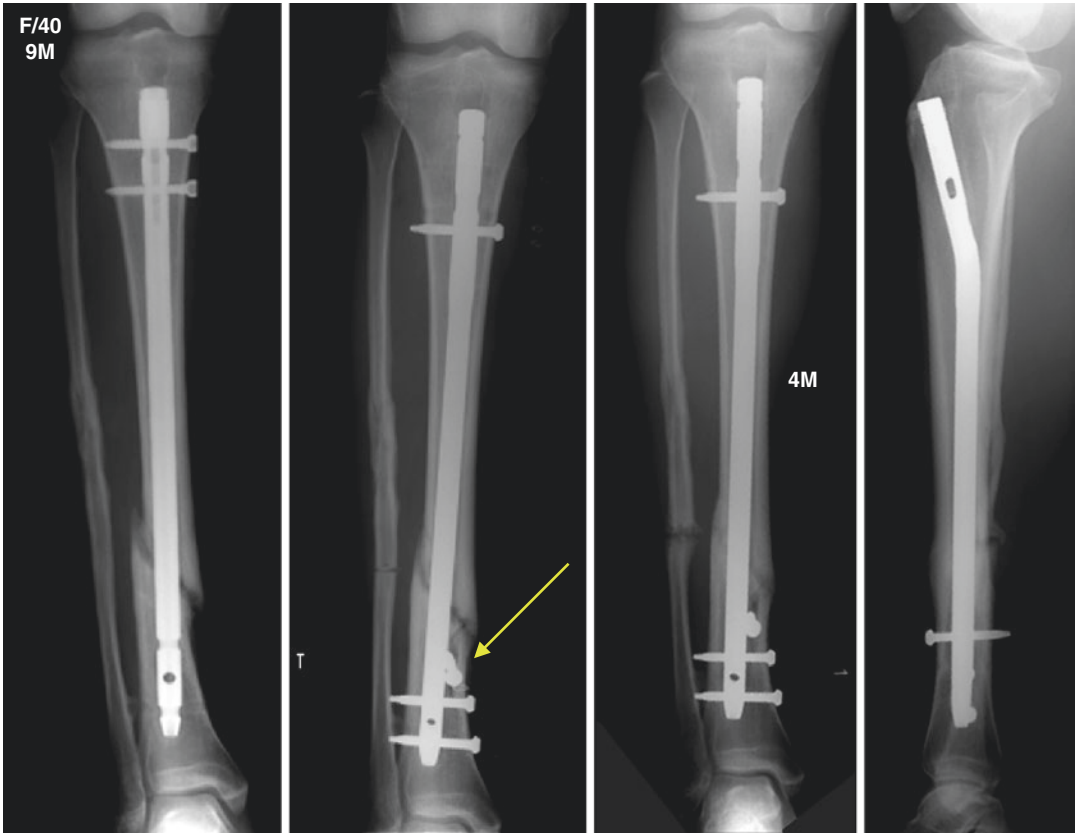


Fig. 4.22 Correction of malalignment and nonunion by exchange nailing technique with a Poller screw. A 9-month-old nonunion with malalignment is difficult to treat with a simple exchange nailing technique alone. An osteotome of the fibula and a Poller screw insertion was

necessary to correct the varus malalignment and a lateral displacement of the distal tibial fragment. A Poller screw (long arrow) was inserted on the concave side of the distal fragment before the insertion of a new nail. Varus deformity was corrected and nonunion healed in 4 months

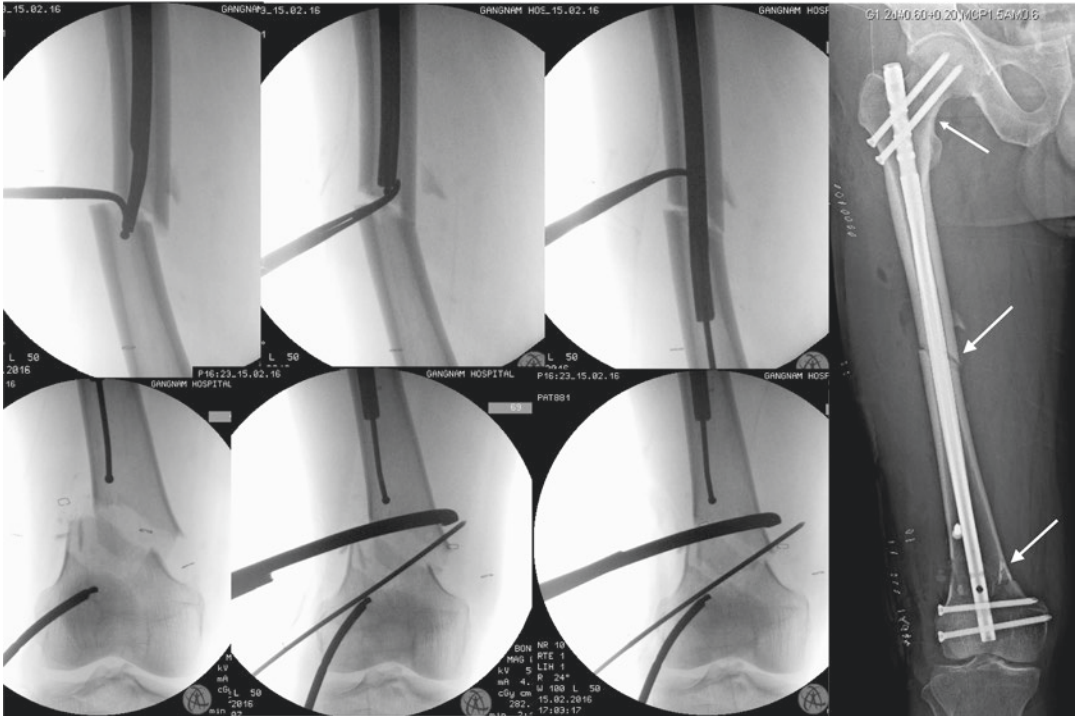


Fig. 4.23 Problems in segmental fracture. One of the biggest problems in the segmental fracture is difficulties in getting adequate traction. Due to insufficient traction, a reduction finger was unable to pass through the distal medullary canal. With the help of the hemostatic forceps leverage technique, (Fig. 4.17), length was restored, and passage of the reduction finger was permitted (upper left column). Ugly displacement at the supracondylar area was impossible to be reduced by the ordinary method. A collinear clamp was used to approximate the fragments gradually, and they were fixed with a temporary pin. A

Schanz pin was inserted at the lateral femoral condyle for manipulation (lower left column). A Poller screw was inserted on the lateral side of the nail in the middle fragment to keep the nail in the center of the medullary canal. Proximal interlocking screws were inserted into the femoral head and neck due to undisplaced ipsilateral femoral neck fracture (a white arrow in the femoral neck). Injury around the knee joint (for example, posterior cruciate ligament avulsion fracture, patellar fracture, supracondylar fracture of the femur) is a risk factor of occult ipsilateral femoral neck fracture (right image, see Chap. 5)

Fig. 4.24 Correct method of measuring femoral anteversion. Dried femora are placed on the table as shown in the upper column. The posterior aspect of both femoral condyles must touch the table surface. Then, the pictures are taken from the proximal aspect. The inclination angle of the femoral neck and head is an anteversion of each femur by definition. The anteversion of the left side femur is 15° and the right one 0°

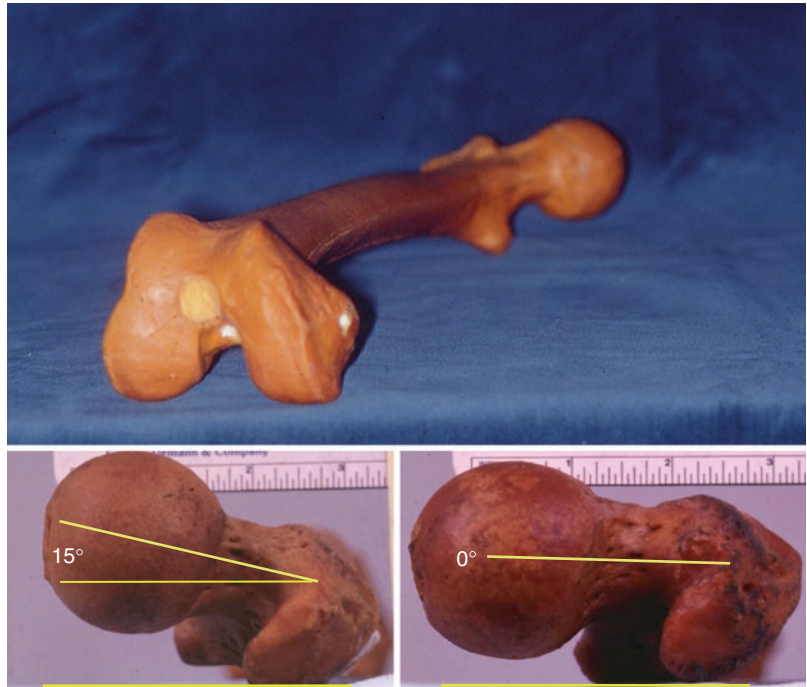
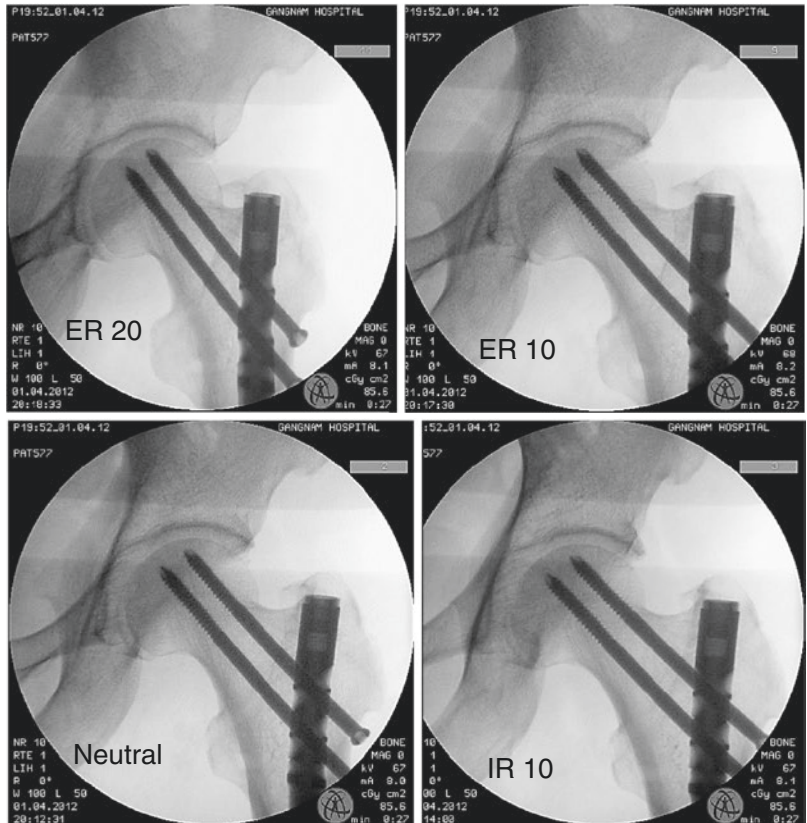


Fig. 4.25 The shapes of lesser trochanter in the hip AP view in the various angles of hip rotation. The lesser trochanter is prominent when the proximal femur is rotated externally. *If the hip AP is taken with the patella forward, it implicates that the fractured femur is fixed in internal rotation*



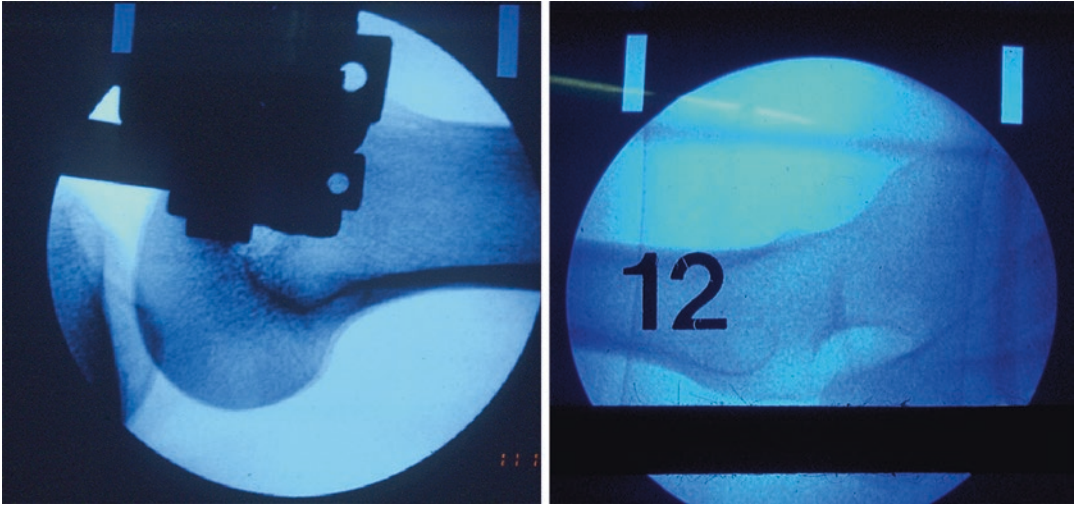


Fig. 4.26 Intraoperative measurement of femoral anteversion. By definition, the inclination of the femoral neck and head is anteversion if the posterior aspects of both femoral condyles overlap in the horizontal beam of the fluoroscopy. This technique is useful in the case of severely comminuted femoral shaft fracture, as shown in the preface of this book. Modern femoral nail (for exam-

ple, ZNN antegrade femoral nail) is manufactured with 15° of anteversion. So, if the femoral neck and head screw are positioned in the center in the lateral view and the circular distal interlocking hole is visible with overlapping of the posterior aspects of both femoral condyles, the femur has anteversion of 15° (see the case figure below)

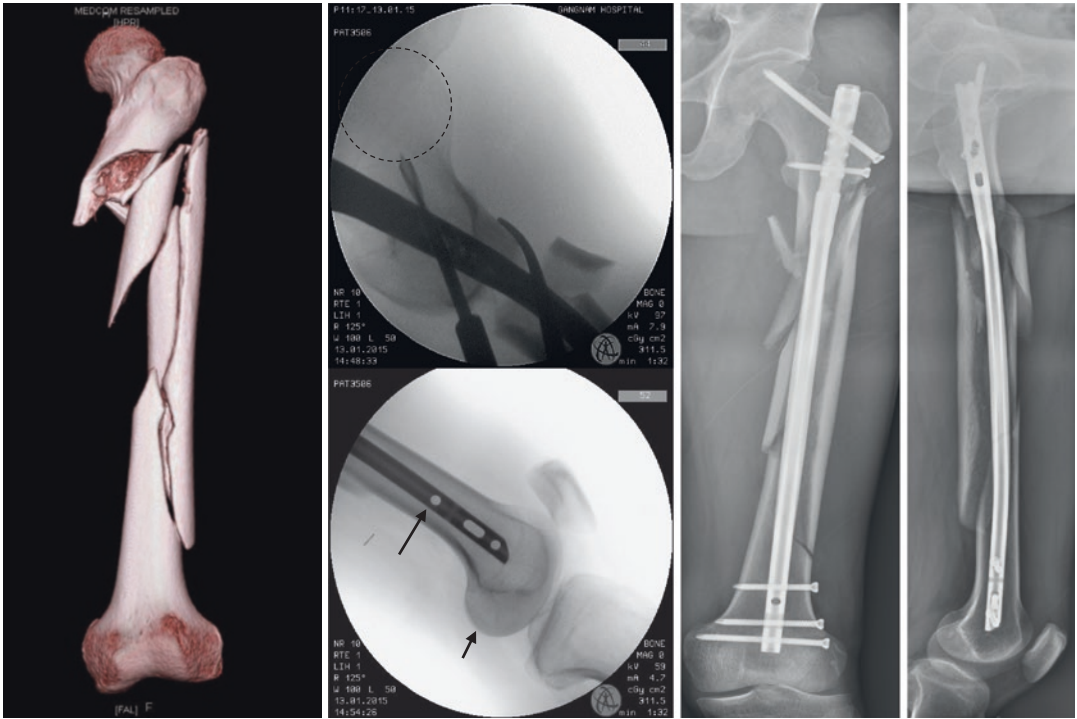


Fig. 4.27 Technique of using an inherent anteversion of intramedullary nail to avoid the malrotation in the highly comminuted femur fractures. Proximal femoral neck and head screw must be located at the center in the lateral view (middle column, upper image). In the distal part of the femur, the fluoroscopy must be manipulated to get a circular distal interlocking hole (long black arrow). Then, rotate the distal femoral fragment by rotation of the foot-plate or skeletal traction device to overlap the posterior

aspect of both femoral condyles (short black arrow in the lower image, middle column). Holding the targeting guide connected to the nail facilitates correction of malrotation deformity while the assistant rotates the distal leg. Insert the distal interlocking screws accordingly. The femoral anteversion matches that of the nail inserted (In this case, the anteversion of ZNN femoral nail is 15°). This technique is beneficial when the shaft fracture is associated with the lesser trochanteric fracture

Table 4.1 Inherent anteversion of the reconstruction nails [15, 18–21]

Brand name	Company	Anteversion (degrees)
T2	Stryker	10
Trigen	Smith & nephew	12
FRN	DePuy Synthes	14
ZNN	Zimmer-Biomet	15

4.4 Reaming of the Medullary Canal

The Küntscher nail was inserted into the medullary canal after the medullary reaming. The purpose of medullary reaming is to insert a large

diameter nail which provides more nail strength and more significant contact areas with the femoral shaft. However, medullary reaming violates medullary circulation. In addition, the inadequate reaming procedure may cause excessive embolism of medullary contents and heat necrosis. In that context, unreamed IM nails were popular in the late twentieth century due to shorter operation times and minimally invasive procedures. However, after reamed IM nailing, overall results are better than those of unreamed ones. Thus, insertion of a reamed interlocked femoral nail after minimal cortical reaming has become the major trend in femoral nailing [7, 8, 11, 22–24]. After successfully positioning the ball-tip guidewire into the center of the femoral

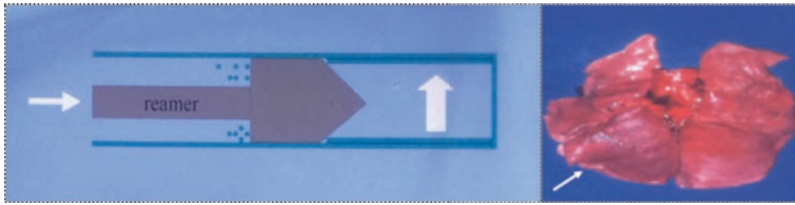


Fig. 4.28 Pulmonary embolism of the medullary contents in forceful reaming. The reamer head acts like a piston within a syringe. So, the IM pressure in the distal medullary cavity (large white arrow on the left image) may increase if the reamer head advances fast (small white arrow). The green droplets indicate cortical reaming

debris expelled behind the reamed head. Rapid advancement may cause pulmonary embolism of the medullary contents, as shown in the lung of the canine fracture model. Congestion in the right lower lobe (small white arrow on the right image) is caused by pulmonary embolism after rapid cortical reaming

condyle through the medullary canal, the reaming process can be started from 7 mm (diameter of the reamer head) end-cutting reamer. Then the reamer size can be increased by 1 mm until it touches the endocortex (the inside layer of the cortex). I prefer an additional 0.5–1.0 mm increment in reaming for proper contact between the nail and endocortex. The edges of the reamer head must be sharp and rotate fast. It must be advanced slowly within the medullary canal to prevent heat necrosis and embolism of medullary contents. Use of ball-tip guidewire is mandatory to withdraw the broken reamer. It is also helpful in the case of reamer head jamming. In the past century, the reamer shaft was made of a spring coil, so reverse rotation (counterclockwise rotation) of the motor uncoils the reamer shaft. The modern reamer shaft is made of a hollow cylinder (stainless steel) so reverse rotation is possible when the reamer head is jammed in the medullary canal.

The IM pressure in the distal medullary cavity may increase if the reamer head advances too fast (Fig. 4.28). I prefer making a ventilating hole at the distal femoral shaft in case of subtrochanteric fracture (long distal fragment) and prophylactic femoral nailing for the incomplete atypical femoral fracture to decrease the IM pressure during the reaming process. Careless rapid reaming may

cause pulmonary embolism of the medullary contents, as shown in the lung of the canine model (Fig. 4.28) [25].

The shape of the reamer head is also critical to decrease the medullary pressure. The figure shows the difference in the distance between the reamer core and the cutting edge. It must be good enough to expel the reaming debris behind (Fig. 4.29) [25, 26].

The careless reaming causes cortical heat necrosis. It seems harmless in the early postoperative period but eventually results in nonunion because of the necrotic sector in the cortical bone. Therefore, wide debridement of necrotic tissue, including cortical segment and reconstruction of the defect, is necessary (Fig. 4.30) [27–29].

The Reamer Irrigator Aspirator (RIA; Synthes) is a surgical instrumentation system that uses negative pressure to circulate fluid through the intramedullary canal during reaming of long bones (Fig. 4.31). Compared to the traditional methods of reaming, the RIA is designed to lower intramedullary pressure and temperature in order to reduce the incidence of fat embolization and thermal necrosis. The RIA system is also commonly used to collect autologous bone grafts as an alternative to iliac crest bone graft [30, 31].

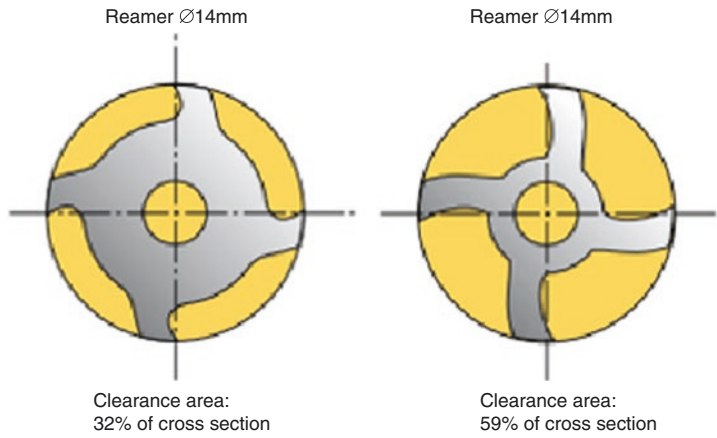


Fig. 4.29 Reamer head. The difference in the distance between the reamer core and the cutting edge is shown. The distance must be good enough to expel the reaming debris behind, namely the clearance area. Compare the clearance areas between the two reamer heads, which

determine IM pressure during reaming process. For example, the right Bixcut reamer increased the clearance area by more than 80% in 14 mm reamer head compared to that of the conventional reamer (Stryker, Bixter reamer system) [26]



Fig. 4.30 Heat necrosis of the cortex after reaming in the narrow medullary canal. A 23-year-old lady sustained a short spiral fracture at the distal tibia after slipping down (a). She underwent closed reduction and internal fixation with a reamed interlocked tibial nail. One year after the operation, the fracture seemed to get united with the periosteal callus, and the IM nail was removed. However, thinning of the diaphyseal cortex suggests excessive corti-

cal reaming due to the narrow medullary canal (b). One year after the removal of the nail, the CT image shows nonunion due to failure in remodeling around the fracture site (c). The nonunion site was necrotic in the segment, so wide debridement was necessary. Autoiliac bone graft and plate osteosynthesis with a locking plate were performed (d). One and a half years after the reconstruction surgery, the bone defect was healed (e)



Fig. 4.31 Reamer Irrigator Aspirator (RIA) system. Upper right image: reamer head with ball-tip guidewire inside, lower right image: harvested autogenous bone [30, 31]

IM nailing is the optimal solution in specific metabolic bone diseases. It can be performed in some cases of autosomal dominant type II (AD II) osteopetrosis with special care on reaming. In AD II osteopetrosis, the medullary canal is extraordinarily narrow and obliterated in some segments. Therefore, it needs careful preoperative planning and slow but steady procedures confirming safety step by step. Evaluation of the medullary canal size using CT axial views is mandatory. Since reaming of hard cortical bone is necessary, slow reamer advancement with high RPM (revolutions per minute) is crucial. See Chap. 11 for details (Fig. 4.32) [32].



Fig. 4.32 Medullary reaming for IM nailing in the autosomal dominant type II osteopetrosis patient (see Chap. 11). A 33-year-old male patient sustained a subtrochanteric fracture after a simple fall. Obliteration of the IM canal is evident in the serial axial CT images of the femur in this AD II osteopetrosis patient. To protect the surgical implant, we decided to fix this fracture using IM nail rather than plate because the defects in osteoclast function take several years to remodel. The main obstacle in IM nailing was the obliteration of the medullary canal. The

entry site and medullary canal were searched and prepared with a 4.9 mm long drill bit for 6 mm screw for reconstruction nail. Once the drill advanced a few centimeters, I replaced it with a ball-tip guidewire and reamed the canal sequentially with 0.5 mm of increment. Since the ball-tip guidewire cannot penetrate the medullary cavity, a long drill was used in every step to open the canal for a few centimeters. Callus formation and healing are evident after IM nailing [32]

4.5 Insertion of the Femoral Nail

After adequate reaming of the medullary canal, the femoral nail can be advanced without difficulties. A loud hammering sound indicates that something is wrong. Smooth advancement of the nail by each blow of a hammer is essential. In case of excessive femoral bowing, it is necessary to rotate the femoral nail externally while it passes the curve's apex (see Chap. 8) [33]. In a long oblique or spiral fracture at the isthmus, the flexible reamers move like snakes in the fracture zone, missing one cortex. Unreamed portion in the inner cortex (bump) also causes bursting of the cortex (Fig. 4.33).

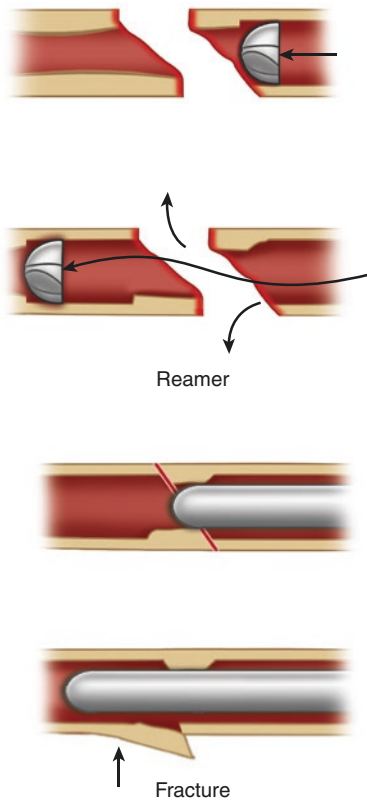


Fig. 4.33 Bypass of the reamer and ineffective reaming in the long oblique fracture. The reamer heads lose contact with the cortex within the fracture zone in case of long oblique or spiral fractures around the isthmus. Once the advancing nail reduces the fracture, the unreamed cortex interferes with the advancement of a nail or causes a fracture eventually. It may not be a significant complication in interlocked IM nailing, but it is advisable to expect it and explain it to the patient before the surgery

Hard endosteal callus in case of atypical femoral fracture after long-term bisphosphonate intake may also cause jamming or bursting of the cortex. Therefore, it is sometimes necessary to remove it using a long narrow chisel to widen the medullary canal (Fig. 4.34). Otherwise, it may also cause bursting of the femoral cortex during the hard insertion of a femoral nail [33–35].

If the fracture locates in the distal part of the femoral shaft, the nail tip must be placed in the femoral condyle for distal interlocking. How deeply can the nail be inserted? The nail tip can be advanced until it touches the V-shaped corner, which is made by the upper intercondylar articular and the lower Blumensaat lines. An undisplaced intercondylar fracture, usually an extension of the primary distal femoral fracture, can be fixed with one or two lag screws before femoral nailing (Fig. 4.35).



Fig. 4.34 Hard endosteal callus that interferes with the medullary reaming. An 80-year-old lady sustained left atypical femoral shaft fracture and right Colles' fracture and was treated by IM nailing and plating, respectively. Tc^{99m} bone scan shows multiple rib fracture and impending atypical femoral fracture on the right femoral shaft (small circle). Due to the propagation of a lateral crack to the midline of the femoral axis, prophylactic nailing is

indicated. Hard endosteal callus and sclerotic fracture margin interfere with the passage of a ball-tip guidewire and reamer (large circle). Opening the medullary canal was necessary using a 4.9 mm long drill bit. The introduction of a ball-tip guidewire was possible, and slow sequential reaming with end and side cutting reamers were necessary for IM nailing

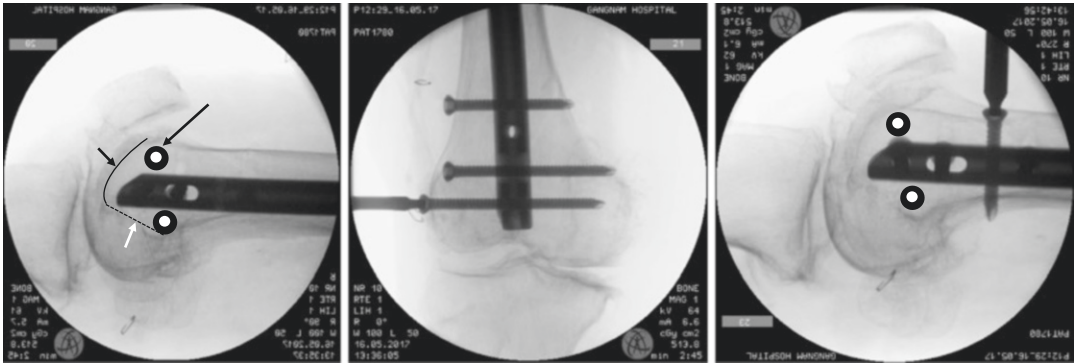


Fig. 4.35 Intraoperative fluoroscopic images depict the position of the nail tip, distal interlocking screws, and lag screws (long black arrow). The nail tip can be advanced until it touches the V-shaped corner made by the upper

intercondylar articular (small black arrow) and the lower Blumensaat (white arrow) lines. An undisplaced intercondylar fracture can be fixed with the cannulated lag screws (long black arrow) before femoral nailing

4.6 Mode of Interlocking

In the late twentieth century, most nails were equipped with static round holes alone; therefore, removing all interlocking screws from one main fragment was inevitable to achieve the dynamization effect. Advocates for routine dynamization believed that load-bearing on the fracture callus promoted fracture healing and rehabilitation of patients. However, Brumbeck et al. reported that most fractures were healed when treated with the static mode; thus, routine dynamization was not indicated. Moreover, the dynamic unlocking mode sometimes resulted in angular instability and excessive shortening due to displacement of the undetected fracture line in 10% of patients. Therefore, the static mode became the standard method of interlocking fixation in femoral nailing [4, 23, 36].

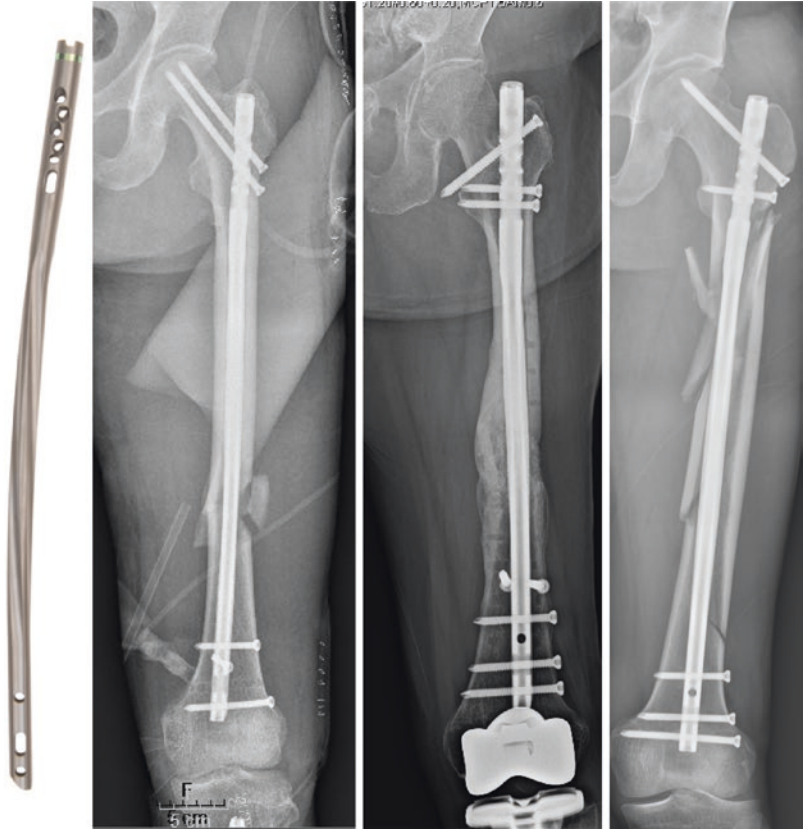
Modern femoral nail systems usually provide dual options for interlocking fixation, namely dynamic and static modes, in both the distal and proximal portions. There is one dynamic hole in each proximal and distal portion. The dynamic mode is subclassified into unlocking (no interlocking screw fixation) and dynamic locking (interlocking screw fixation at the dynamic hole only) modes. The static mode is subclassified into static locking (interlocking screw fixation at the static hole only) and hybrid locking (interlocking screw fixation at both the dynamic and

static holes) modes. In the status of hybrid locking mode, conversion to the dynamic locking mode (dynamization) can be achieved easily by removing the static interlocking screws located beside the dynamic interlocking screw. *Do not forget to remove the ball-tip guidewire before drilling for interlocking!*

Modern femoral nails also provide various proximal and distal interlocking options to treat associated proximal (femoral neck and trochanteric) and distal (supracondylar) fractures (Fig. 4.36). Proximal interlocking screws are usually inserted through the holes in the attached targeting guide. Please choose the best option for proximal fixation among them.

1. One of the difficulties in proximal interlocking is the correct positioning of the femoral neck and head screw (reconstruction screw). Unlike insertion of the oblique screw from the greater trochanter to the lesser trochanter, the reconstruction screw needs unique technique, especially when two reconstruction screws must be inserted. The level of the proximal interlocking holes in the nail must match with that of the femoral neck and anteversion. To insert the long reconstruction screw properly in the femoral head, the tip of the reconstruction screw must be placed at the center of the femoral head in the lateral view. We found a helpful tip for correcting a guide pin that is

Fig. 4.36 Various patterns of the proximal and distal interlocking. Combining interlocking screws in different directions is possible in modern femoral nails. In the proximal portion, reconstruction and transverse interlocking screws can be inserted through the targeting guide according to the fracture configuration. Distal interlocking screw holes are oriented in latero-medial and anteroposterior directions. Additional stability can be obtained by inserting Poller screws beside the nail in the osteoporotic bone. Some holes are designed in oblong (or oval) shape so that dynamic interlocking is possible in femoral nailing and exchange nailing



inserted in an improper position. The movement of the guide pin in the posterior direction in the lateral view is associated with inferior migration of the guide pin in the AP view. The greater the anteversion of the femur, the more significant the shift of guide pin in AP view per degree of correction in the lateral view (Fig. 4.37) [37].

2. Skidding the guidewire frequently happens, especially in young patients. Principal compression trabecula is dense, so a guide pin may miss the tract and bend upward. Fig. 4.38 shows the solution to this troublesome problem.

(a) Skidding the guidewire for a lag screw frequently happens, especially in young patients. Principal compression trabecula is dense, so a guide pin may miss the tract and bend upward. Forceful reaming would damage and break the guidewire (white arrow in Fig. 4.38).

(b) Withdraw a lag screw reamer and a guide pin. Confirm the damage to the guidewire. If damaged, it must be replaced.

(c) Then, insert the lag screw reamer through the targeting guide and confirm the AP and lateral view position. If the imaginary extension line from the lag screw reamer hits the intended point in the femoral head, insert the guide pin.

(d) Tap the end of the guide pin and advance the reaming along the guide pin for a few centimeters. Repeat the procedure if necessary.

(e) Keep identifying the tip of the guide pin in AP and lateral views.

(f) Confirm the final position of the lag screw.

Distal interlocking screw insertion can be performed using one of the three methods: a) freehand technique using targeting wand (Figs. 4.39 and 4.40), b) distal targeting device (Figs. 4.11, 4.41 and 4.42), and c) electromagnetic tracking device (Fig. 4.42).

“Shift Phenomenon”

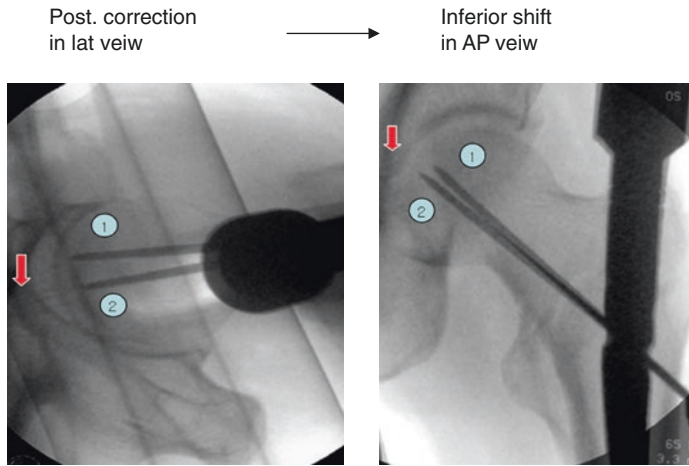


Fig. 4.37 Shifting phenomenon of the guide pin. When the number 1 guide pin is inserted into the center of the femoral head in the AP view but in the anterior one-third of the femoral head in the lateral view, correction is necessary to move the guide pin 1 to the center of the femoral head in the lateral view (number 2). This movement

results in inferior migration of the number 1 guide pin in the AP view (final position number 2). Similarly, anterior redirection of the guide pin in the lateral view results in superior migration (shift) of the guide pin in the AP view. This shift phenomenon becomes bigger in severe anteversion [37]

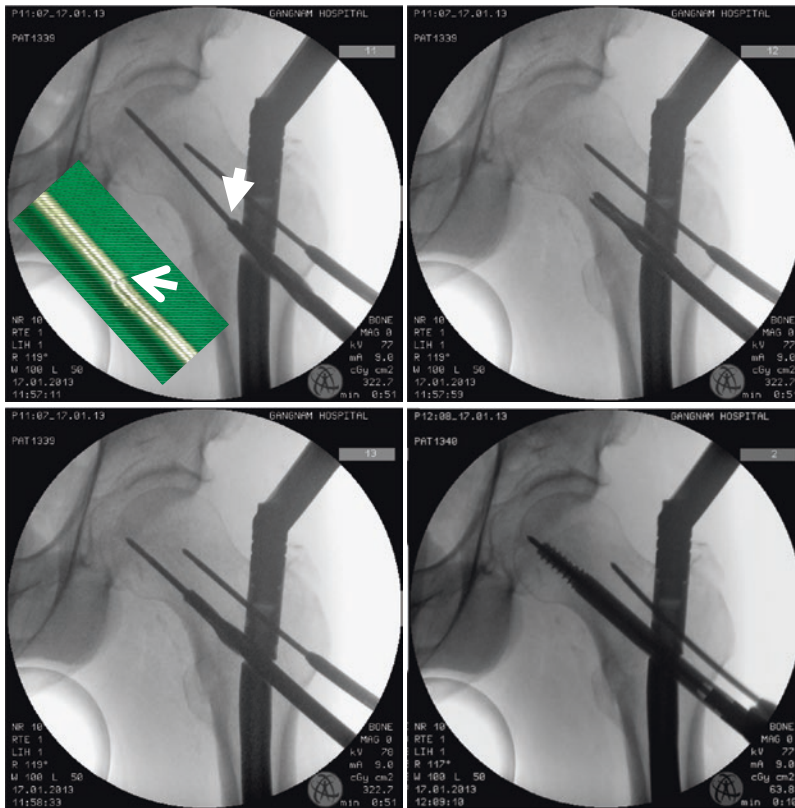


Fig. 4.38 The method of overcoming the skidding phenomenon of the guidewire caused by primary compression trabecula

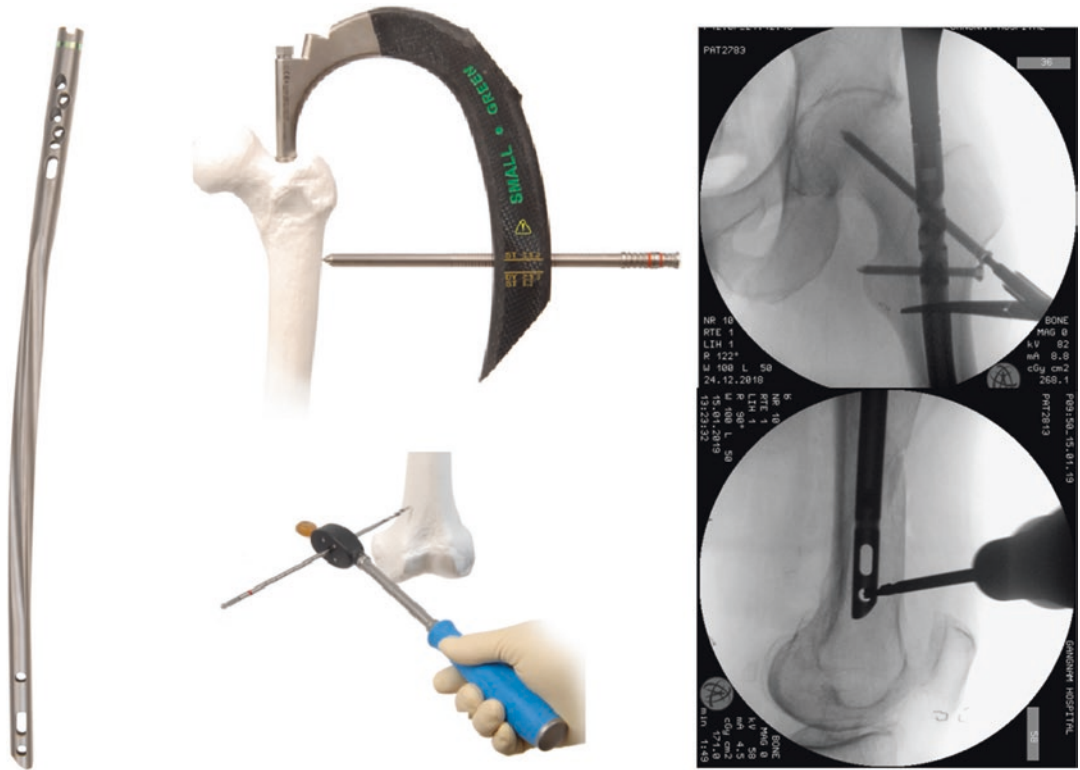


Fig. 4.39 Freehand technique for distal interlocking screw insertion (Targeting of the distal interlocking hole under the control of fluoroscope). Proximal interlocking is performed through appropriate holes in the targeting guide (upper middle and right images). In the distal portion, the freehand technique using a wand is popular. First, adjusting the fluoroscope to visualize the distal hole in a com-

plete circular shape is necessary. Then, the tip of the wand pin or the drill tip is approached to the hole perpendicular to the long axis of the limb or nail (lower middle and right images). Otherwise, the overlap of the nail and the pin interferes with the correct judgment of the tip position. Once the tip hits the center of the distal interlocking hole, tilt the handle to align with the fluoroscopic beam [21]

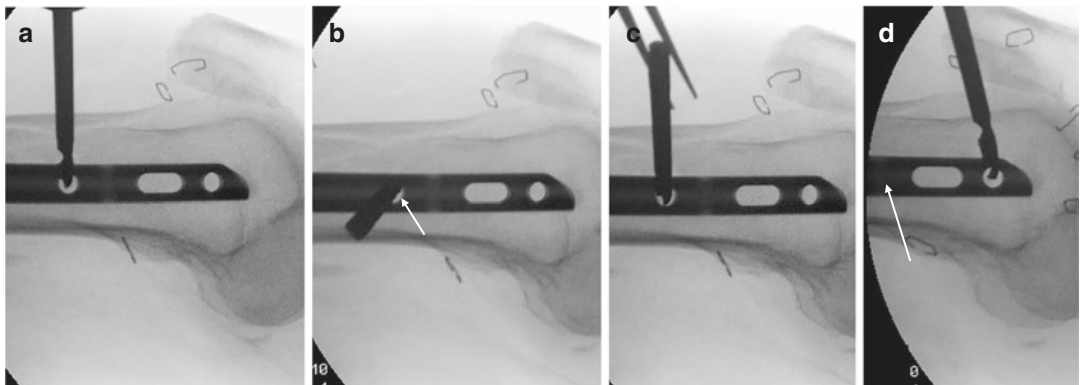


Fig. 4.40 Technique of correcting the misdirected drill bit. Even though the drill tip starts from the center of the circle (a), skidding of the tip sometimes occurs, and the drill tip may fail to exit from the interlocking hole (b). Disconnect the drill bit from the motor and check the hole using fluoroscopy. There is a small void in the inferior dis-

tal part of the interlocking hole (short white arrow). Adjust the drill direction to the void area and restart drilling (c). Interlocking hole is made, and the screw is inserted (long white arrow). Interlocking procedure in the most distal hole is more difficult than in the proximal one due to the distance from the starting point to the interlocking hole (d)



Fig. 4.41 Distal targeting device. Distal interlocking can be performed with minimal fluoroscopic exposure of the hand if the distal targeting device is available. Usually, slight anterior or posterior adjustment is necessary, and it is convenient to hit the hole with low radiation exposure (Distal targeting system, operative technique, Stryker) [38]

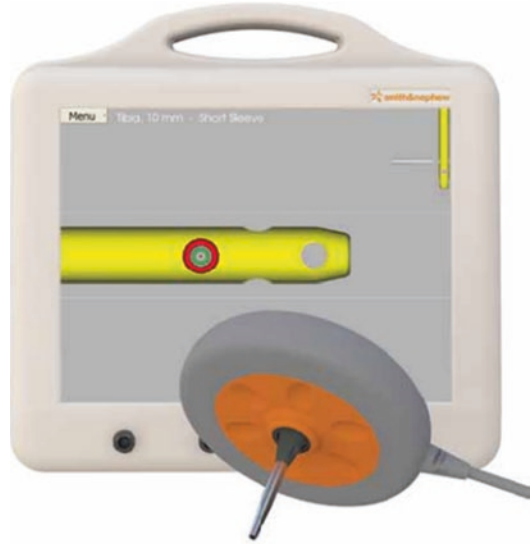


Fig. 4.42 The Smith & Nephew TRIGENT™ SURESHOT™. Distal Targeting System is intended to be an intraoperative image-guided localization system. It is a computer-assisted orthopedic surgery tool to aid the surgeon with drill positioning for screws during intramedullary nail implantation [39]

4.7 Summary

Let's review the IM nailing procedures through the following Figs. 4.43, 4.44, and 4.45.

Fig. 4.43 What kinds of problems are expected during IM nailing? What are the tactics for those problems?



M/35, MVA, TD #1 day

What kinds of problem do you expect during IM Nailing?

1. ER and abduction of first fragment
2. Difficulties in reduction
3. Extension deformity of fourth fragment
4. Nail length? Do you have proper size?

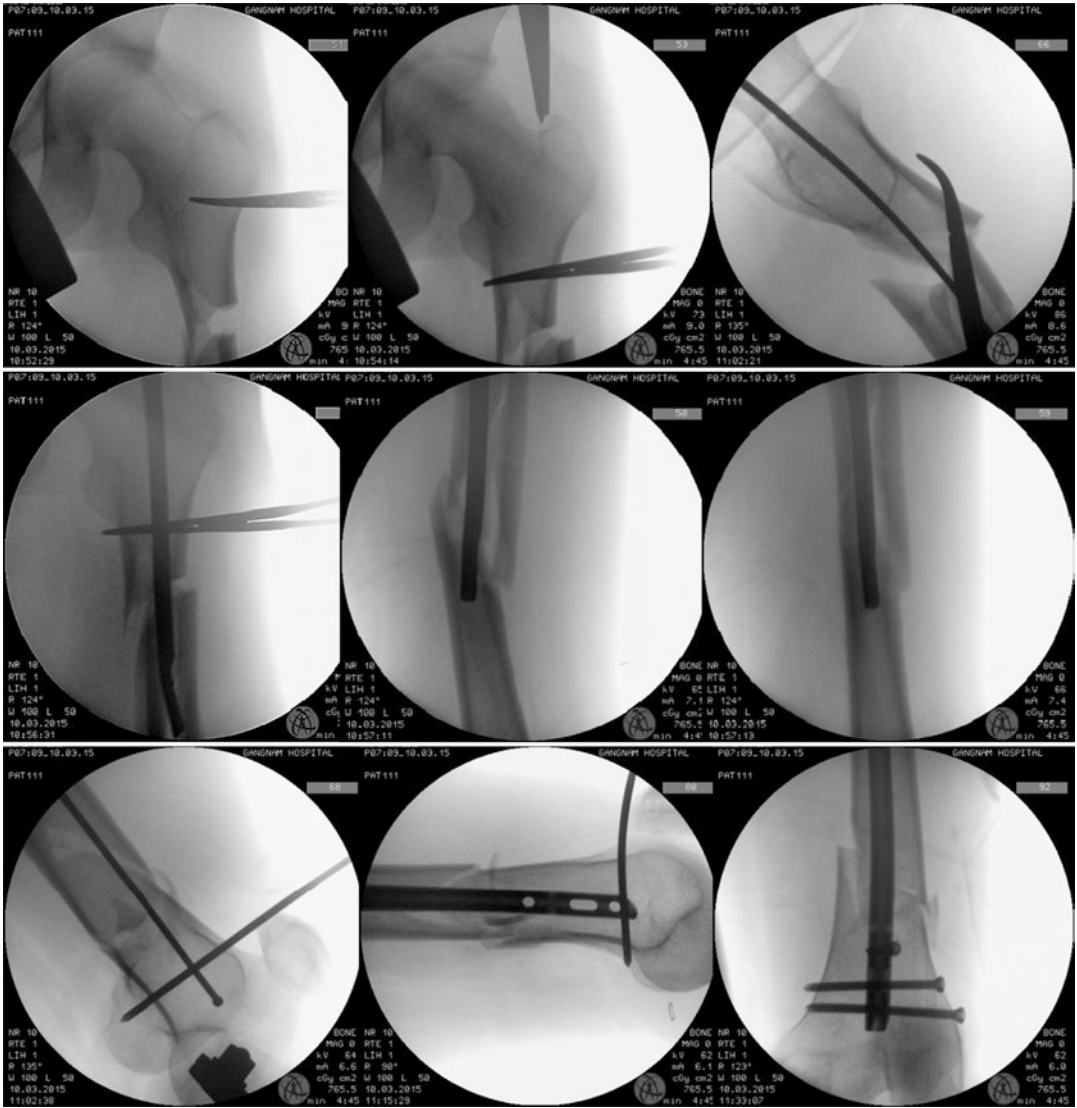


Fig. 4.44 Operation Procedures. It is crucial to derotate the proximal fragment, which is rotated externally. The use of long curved forceps is quite helpful in correcting flexion, abduction, and external rotation deformity of the proximal fragment. First, the deformity of the proximal fragment must be corrected to obtain a proper hip AP view. Then the medial slope of the greater trochanter and trochanteric fossa become visible. Advance the guidewire into the trochanteric fossa and check the lateral view (serial images in the upper column). The entry site is confirmed and reamed the proximal fragment with a trochanteric reamer. Then introduce the reduction finger or similar rod to get proper alignment. Serpentine movement of the curved reduction fingertip can catch the entry of the medullary canal of two middle fragments (serial images in the middle column). The short distal fragment is hyperextended due to heavy gastrocnemius muscle. A Steinmann pin is inserted on the femoral condyle to counteract the

gastrocnemius muscle tension to align the distal fragment in the lateral view. The use of a Poller screw in the coronal plane is another option. Keep the reduction until the nail advances to the endpoint as scheduled. The nail was not inserted deep enough into the distal fragment in this case because the longest nail we had was still short for this patient. Insert the distal interlocking screws in AP and latero-medial directions. Two Poller screws could be added besides the nail if the fixation was not firm enough for early knee motion (serial images in the lower column). Check hip AP view in full internal rotation for occult ipsilateral femoral neck fracture and the range of motion of both hip joints to avoid malrotation before the patient leaves the operating room! At the femoral neck, there was no suspicious radiolucent line suggesting an ipsilateral femoral neck fracture in this patient. 15° of femoral anteversion were obtained using inherent anteversion of the femoral nail

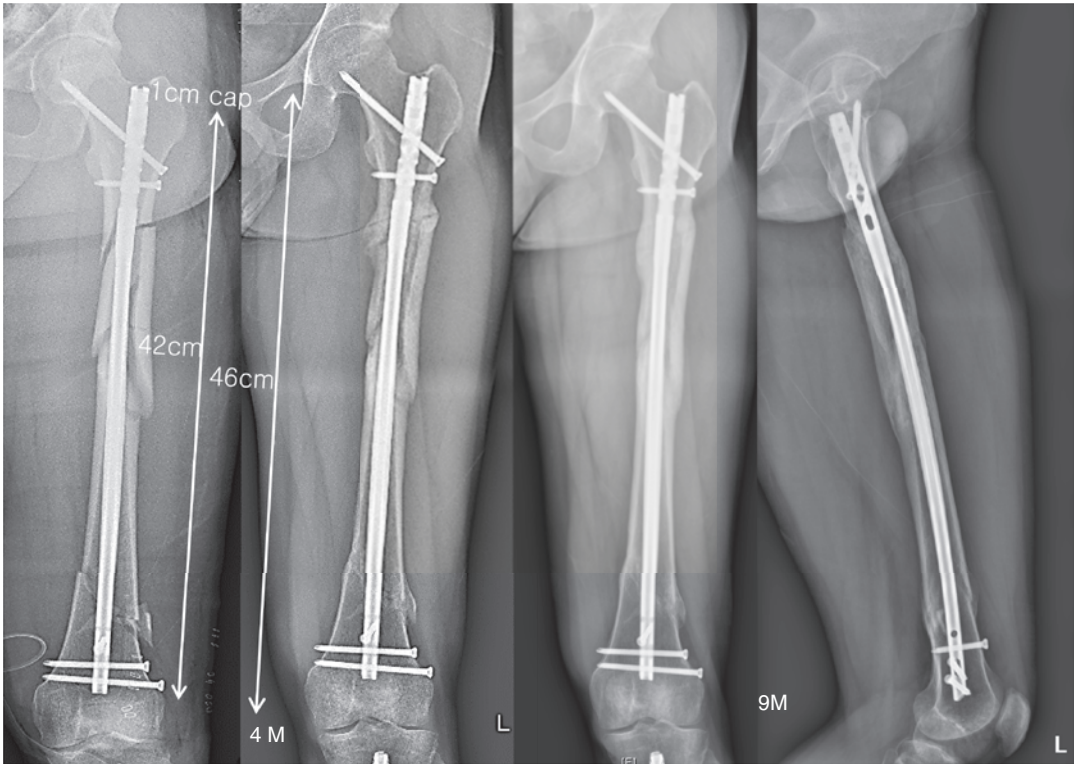


Fig. 4.45 Postoperative and follow-up radiograms. Postoperative radiogram shows the anatomical alignment of the fragments and firm fixation of the proximal and distal fragments. We needed a 46 cm antegrade femoral nail, but a 42 cm nail was the longest one we had at the hospital. The nail tip was not deep enough into the femoral con-

dyle for that reason. Therefore, 1 cm cap was used (we might not be able to put a reconstruction screw into the femoral neck and head if we used a 2 cm cap). Early callus formation is visible 4 months after IM nailing. The solid union was obtained in 9 months

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