Femoral Malrotation Following Intramedullary Nail Fixation

Abstract

Intramedullary nailing of femoral shaft fracture can result in inadvertent malalignment. Malrotation is the most common cause of deformity, but it is underrecognized, in part because of the difficulty in accurately assessing rotation as well as the variation that exists in normal anatomy. The consequences of femoral malrotation are not completely understood. However, initial biomechanical studies suggest that it causes a substantial change in load bearing in the affected extremity. Clinical examination, fluoroscopy, and ultrasonography are useful in measuring femoral rotational alignment intraoperatively and postoperatively. CT is useful in the identification of the degree of malrotation and in surgical planning.

Intramedullary (IM) nailing is the standard of care for the management of femoral shaft fracture in adults.1 This technique can be done with closed or open reduction in conjunction with reaming and interlocked IM nailing. High union rates and early limb mobilization are two advantages of IM nail fixation. Although complication rates are low, pitfalls exist. Malalignment during surgery may lead to malunion. Deformity may include improper length, malrotation, and angular malalignment.1,2 Deformity, however, may be avoided.

Malrotation is the most difficult complication to detect radiographically and clinically, and it is often underappreciated.3 Postoperative malrotation is evident in up to 27.6% of femoral shaft fractures managed with IM stabilization (range, 2.3% to 27.6%).1,4,5 Anatomic rotation is patient-specific. Each person has unique femoral anteversion, and accurate assessment of rotational alignment requires comparison of the injured and uninjured extremities. This can be done preoperatively or intraoperatively if the uninjured leg is prepped. Following fracture reduction and nail insertion, failure to place proximal and distal interlocks can result in malrotation.

Malrotation is often determined by indirect means, such as assessment of cortical thickness and alignment on intraoperative imaging.3 Fractures at higher risk of malrotation include transverse, segmental, and comminuted patterns. Fractures associated with bone loss are also at higher risk of malrotation. Fluoroscopic assessment of rotational alignment is limited in the setting of these fracture variables. The narrow field of view associated with fluoroscopic imaging further limits the ability to assess femoral alignment (Figure 1).

Clinical assessment is an inconsistent method of judging rotation. Assessment of rotation by comparison of the injured extremity with the unaffected extremity leads to missed malrotation measuring >20° in 42%
of patients evaluated supine and 25% of patients measured prone. Jaarsma and van Kampen reported that the 95% confidence interval (CI) of the clinical examination compared with CT scan was ±19° with the patient prone and ±21° with the patient supine. Previously reported malunion rates should be critically evaluated because they typically relied on clinical assessment of rotation. Improved techniques are required to assess and control rotation while reducing femoral shaft fractures.

**Femoral Version**

The rotational profile of the femur is the amount of internal and external rotation that occurs through the axis of the femur as it rotates through the hip. The arc of motion in the hip joint determines the total amount of rotation. The amount of internal and external rotation is determined by the degree of motion at the femoroacetabular articulation together with the femoral version. Version is the angle of the femoral neck relative to the transverse axis through the femoral condyles. The angle of the femoral neck increases from zero in utero to 30° to 50° of anteversion at birth. Gradual external rotation of the femoral neck continues until adult anteversion is achieved at skeletal maturity.

Femoral anteversion is patient-specific and varies considerably. In a cadaver study, Kingsley and Olmsted reported that 25% of adult femurs had anteversion measuring 5.5° to 10° and that 66.3% of all adult femurs measured 0° to 15°. Significant bilateral differences in anteversion have been found in patients with no history of trauma. Reikerås et al reported a difference in bilateral anteversion of up to 11.8° in 48 pairs of normal cadaver specimens (95% CI).

Accurate, reliable measurement of anteversion is a challenge to achieve. Even with the use of axial CT scan, accurate measurement of version in two dimensions is difficult because of the complex proximal femoral anatomy and its relation to the distal femoral condyles. Several methods have been proposed to measure version of a fractured femur. Bråten et al measured femoral version postoperatively using an ultrasonography-based tilted transducer technique and compared these results with the noninjured side. Malrotation was defined as a rotational difference ≥15° between the injured and noninjured side. In another study, Bråten et al categorized rotational differences of 10° to 14° as “possible torsional deformities,” whereas differences of <10° were considered to have “no significant torsional deformity.” Brouwer et al found that 6% of uninjured subjects had variations of up to 10° between the left and
right femurs. The upper limit of normal anatomic variation (2 standard deviations) is 11° to 13° of anteversion. In the absence of prior trauma, some persons have anteversion differences between limbs of 15°.²⁷ Bråten’s categories of rotational differences are based on this known variation of anatomy.

### Functional Significance

Gait disturbance is often incorrectly attributed to incomplete rehabilitation in the early postoperative period rather than to malrotation.¹⁸ Malrotation does not cause symptoms in a predictable manner. Patients have individual thresholds with regard to tolerance of malrotation. In 21 patients with torsional deformity of ≥15°, only 8 had related complaints.³ Three of 26 patients with 10° to 14° malrotation had complaints. The amount of normal hip rotation as well as the direction of deformity likely affects tolerance for malrotation. Other variables may include patient activities and expectations.

Foot progression analysis indicates that external malrotation is more difficult to overcome than internal malrotation.¹⁸ Patients with external malrotation ≥20° scored worse on the Oxford 12-item knee questionnaire and had more difficulty climbing stairs. Stahl et al¹⁹ reported that patients with malrotation ≥26° had difficulty walking long distances. External rotation of the femur results in posterior displacement of the mechanical axis in the sagittal plane.²⁰ Long-term effects of this shift in mechanical axis are unknown. Rotational deformity of the knee has been implicated in osteoarthritis of the knee. Patellofemoral arthritis is related to increased external rotation of the femur.²⁰ Contact pressures in the patellofemoral joint are greater with external malrotation than with internal malrotation.²¹ These pressures were greatest at 30° and 60° of knee flexion. These data suggest that malrotation has an effect on knee function and wear, especially in the patellofemoral joint.

### Preventing Femoral Shaft Malrotation

Preoperative planning is the most important aspect of femoral shaft fracture management. High-quality orthogonal views of the fractured femur, including the hip and knee, are obtained to elucidate the fracture location, pattern, and degree of comminution. It is equally important to assess for concurrent fractures of the femoral neck.

Pure transverse fracture patterns such as Orthopaedic Trauma Association (OTA) 32-A3 and Winquist III and IV (OTA 32-C) have a higher risk of malrotation than do other fracture patterns. Radiographic interpretation of rotation in patients with transverse fracture patterns is also challenging. When the reduction cannot be judged to be anatomic, it is difficult to accurately predict correct rotation based on radiographs. In these situations, the patient should be counseled preoperatively regarding the potential for reoperation.

The direction of femoral malrotation is based on which attached muscles are involved. For example, proximal femur fractures tend toward net internal rotation of the femoral shaft secondary to the pull of the iliopsoas muscle, short external rotators, and glutei on the proximal femur. The relative external rotation of the proximal femur results in internal rotation of the distal segment. Conversely, external malrotation can occur in distal femoral fractures secondary to the pull of the adductor muscles on the proximal fragment and the pull of the plantaris and lateral gastrocnemius muscles on the distal fragment. Winquist et al¹ reported a higher incidence of malrotation in proximal femur fractures; however, this finding has not been reproduced.⁹,²²

Patient factors may also contribute to malrotation; however, few studies have investigated these factors. Obesity has not been shown to be a contributing factor in malrotation when rotation is measured clinically.²³ However, a large prospective study indicated that use of a fracture table is associated with increased frequency of internal malrotation compared with manual traction.⁴ In this study, 87 patients with femoral shaft fracture requiring antegrade IM nailing were randomized to manual traction or a fracture table. Twelve of the 42 femurs in the fracture table group were internally rotated >10°, compared with 3 of 45 in the manual traction group (29% versus 7%, respectively; P = 0.007). These findings pertain only to supine patient positioning and the use of skin traction.

Proper patient positioning is essential in the successful reduction and stabilization of femoral shaft fractures. Each position has advantages and disadvantages. The lateral position has been advocated to allow easier access to the nail entry point. However, this position makes it nearly impossible to obtain images of the contralateral limb for intraoperative comparison of rotation. Supine positioning with a bump under the hip, which has been described for IM nailing without the use of a fracture table, may lead to an external rotation deformity.²⁴ This malrotation is caused by forced external rotation of the distal femur during distal interlock placement. Conversely, Tornetta et al²² found no correlation between malrotation and patient positioning in persons treated with IM nailing.

Few authors have investigated malrotation in relation to retrograde ver-
Measurement of Rotation

Fluoroscopic Measurement of Anteversion

Tornetta et al described a technique involving fluoroscopic measurement of the injured and contralateral sides in 22 patients with femoral anteversion. With this technique, the uninjured side must be assessed before surgery. With the patient supine, a true lateral view of the proximal femur is obtained, and the position of the C-arm is noted. The true lateral view delineates the overlap of the medial and lateral cortices of the femoral neck. The leg is held still while fluoroscopy is used to obtain a perfect lateral view of the ipsilateral knee. The perfect lateral view demonstrates overlap of the posterior cortices of the medial and lateral condyles. The difference in the angles of the intensifier determines the femoral version. This same technique is used on the injured leg following placement of the proximal interlocks in the nail. The femoral version is matched to that on the contralateral side, and the distal interlocks are placed.

In a prospective analysis of 12 patients treated with this technique, Tornetta et al used the C-arm to assess anteversion of the healthy extremity intraoperatively and reproduced this anteversion in the injured extremity. They reported average rotational discrepancy of 5° (range, zero to 8°) between the fractured and uninjured sides. This group was compared with 22 patients at the same institution who had previously undergone the same procedure but without the use of intraoperative fluoroscopy-based measurement technique. In these 22 patients, femoral alignment was achieved by rotating the distal fracture fragment until the patella was facing directly up (patient supine positioning) or directly lateral (patient lateral positioning). All 22 patients had routine follow-up, and CT rotational profiles were done to assess rotation. Of this group, 12 patients were left with rotational deformity >10°. Thirteen patients were in external rotation, with an average malrotation of 18° (range, 5° to 61°). Nine patients had internal rotation averaging 12° (range, 4° to 37°). Following data analysis of the group of 22 patients, the authors began using the C-arm method of assessing femoral anteversion intraoperatively. The 12 patients who were then studied prospectively using the C-arm method had an average rotation discrepancy of 5° (range, zero to 8°) as measured by CT scan. Although use of an historical control group introduces potential bias, use of this fluoroscopic method seems to be supported.

Lateral-only Imaging

Lateral-only imaging also requires preoperative measurement of the unaffected side. Fluoroscopy is used to obtain a true lateral view of the femoral condyles (ie, posterior condylar images overlapping). The limb is held in position while the fluoroscopy unit is moved to the proximal femur, where a second lateral view is obtained. Two angles can be measured to show the relationship of the femoral neck with the femoral shaft: the neck-femoral (NF) and the neck-horizontal (NH) (Figure 2). The NF angle lies between the femoral neck and the femoral shaft. The NH angle is measured at the junction of a line that bisects the center of the femoral neck and the horizontal line at the base of the monitor. The NH angle has been demonstrated to more accurately represent the true version in an anatomic study of 20 cadaver specimens. Bråten et al used this technique in a prospective study of 10 patients with femoral shaft fractures. Femoral anteversion measurements...
matched to within 10° in all patients when measured using ultrasonography. The authors also reported that the C-arm could be positioned within 30° to 60° oblique to the lateral image and generate an accurate measurement. Either angle can be used to compare the lower extremities.

**Lesser Trochanteric Profile**

Deshmukh et al²⁶ described a relatively easy method of assessing femoral rotation using the profile of the lesser trochanter on an AP fluoroscopic image. This method can be performed at any time with the patient supine, with or without a fracture table, and it can be performed intraoperatively. The profile of the lesser trochanter on an AP image serves as the basis for comparing the lower limbs. First, a true lateral image of the femoral condyles is obtained. The C-arm is then rotated 90° from that point, without moving the limb. This AP view of the proximal femur is used to assess the profile of the lesser trochanter. The double screen of the image intensifier can be used to compare the sides (Figure 3). This method is not appropriate for lesser trochanteric fractures or bilateral femur fractures, nor should it be used in patients with preexisting hip disease.

This technique was evaluated in a prospective randomized trial of 10 patients with Winquist type III or IV comminuted femoral fracture.²⁶ Five patients were treated with IM nailing with the technique; the other five patients were treated with fluoroscopic fracture alignment and skin-fold assessment. A CT rotational profile was generated for each patient to determine the rotational alignment of the injured side, using the uninjured side as a control. All five patients treated with the lesser trochanteric profile method had <10° of rotational difference compared with the uninjured side (four of the five had <5° of malrotation). In the group evaluated with the fracture alignment method, three patients had malrotation measuring >10°, and two had malrotation measuring >15°. The authors of this relatively small series concluded that the lesser trochanteric profile technique, although not as ac-
curate as the technique described by Tornetta et al.\textsuperscript{22} was helpful and did not substantially increase the amount of surgical time.

**Ultrasonography**

Ultrasonography has been successfully used to measure femoral anteversion and rotation postoperatively.\textsuperscript{16,27-29} In 1990, Terjesen et al\textsuperscript{27} first described the use of ultrasonography for measuring femoral anteversion. This method has proved to be accurate. An ultrasonography probe used with an attached goniometer provides the measurement of the orientation of the distal femoral condyles as well as the femoral neck. The resulting angle is the femoral version. This method was initially performed with the patient supine and with the table bent to allow the knees to be flexed to 90°. The legs were then strapped together in this vertical position, and two scans of each hip were performed. The method of using the head-trochanter tangent on a lateral view of the hip reproducibly adds 10° of anteversion compared with standard orthogonal radiographs, and this correction should be subtracted.\textsuperscript{27}

The Terjesen method has been modified for use in the fracture setting; however, no study has been done on the use of ultrasonography intraoperatively to prevent malrotation. Measurements of anteversion obtained with ultrasonography have been shown to be within 3° of CT-based measurements.\textsuperscript{28} Ultrasonography in the outpatient setting has been advocated to assess postoperative rotation.\textsuperscript{5}

**CT**

CT is used for preoperative and postoperative assessment of femoral rotation (Figure 4). Jeanmart et al\textsuperscript{30} described a reproducible technique used to measure femoral anteversion based on the angle between a line drawn through the center of the femoral neck and a tangent drawn across the posterior aspect of the distal femoral condyles (Figure 5). The line that determines the cervical plane is best measured slightly below the femoral head. At this level, the full thickness of the femoral neck can be visualized.\textsuperscript{14} The line drawn through the center of the femoral neck at this level determines the cervical plane. The condylar plane is accurately defined by the sum of the angles of the anterior and posterior distal femoral condyles. For simplicity and ease of use, the axis of the tangent along the posterior aspect of the condyles can be used.

Clinical use of Jeanmart’s technique has not been entirely predictable. Intraobserver variance of 3.9° and interobserver variance of 4.1° have been reported.\textsuperscript{31} In an attempt to make the procedure easier to apply, an alternative method has been proposed.\textsuperscript{32} Rather than compare the cervical and condylar planes directly, each can be measured relative to the horizontal plane in a single CT slice. The anteversion angles are determined by subtracting the condylar angle from the cervical value (Figure 4).

One limitation of the technique described by Jeanmart et al\textsuperscript{30} is that it cannot be used intraoperatively. However, the use of CT intraoperatively as a means to prevent malrotation has been investigated.\textsuperscript{33} This has not been validated in human subjects, however, and concerns exist re-
garding patient exposure to radiation as well as the availability and cost of equipment. The biggest challenge in determining anteversion is accurate and reliable identification of the axis of the femoral neck. An alternative anatomic measurement of femoral anteversion has been described using CT\textsuperscript{14} (Figure 5).

**Computer-assisted Surgery**

Computer-assisted surgery (CAS) is being used more frequently in arthroplasty and realignment osteotomy procedures. The use of CAS in orthopaedic trauma has also been investigated.\textsuperscript{34,35} In a cadaver study comparing CAS with freehand placement of interlocks in IM nails, freehand placement of interlocking screws resulted in up to 7° of malrotation (range, 4° to 7°), whereas computer-navigated insertion resulted in a 2° rotation (range, 1° to 3°; \( P < 0.05 \)).\textsuperscript{36} Malrotation occurred during drilling of the interlock hole as the drill was redirected when it engaged the nail. Thus, even with the most accurate measurement of rotation, some malrotation may be unavoidable because of the inherent technical aspects of locked nailing. CAS has been noted to add to surgical time in arthroplasty surgery, and equipment costs may be significant. The future of CAS in fracture care remains uncertain.

**Clinical Assessment**

Clinical assessment of rotation is often used in surgical and clinical settings. Rotation is measured by flexing the hip and knee of each lower limb with the patient supine or prone. Prone positioning has been described as offering a more accurate result, but many surgeons prefer the supine position for ease of use.\textsuperscript{9} Each hip is fully rotated internally and externally. If each hip is free of pathology and has a similar amount of total rotation, then side-to-side difference can be attributed to malrotation through the fracture site. For example, 20° of external malrotation alters the profile of the hip so that it has 20° more external rotation from neutral and 20° less internal rotation compared with the other side.

Despite widespread use, clinical assessment of the rotational profile has been shown to be inaccurate.\textsuperscript{1} However, other studies have demonstrated accuracy to within 5° using clinical examination.\textsuperscript{37} The accuracy of clinical examination alone must be questioned in patients with symptomatic complaints consistent with malrotation and in those in whom preexisting hip disease is suspected.

**Surgical Assessment**

Regardless of the technique chosen to assess rotation, each patient must be examined thoroughly following static locking of the IM nail and before he or she leaves the operating room. This systematic examination must assess both rotation and limb length. The knee should be evaluated for ligamentous stability. Radiographic assessment of the femoral neck is required to ensure the absence of femoral neck fracture following fixation.

**Revision Planning and Technique**

No universally accepted guidelines exist for defining the degree at which malrotation becomes significant. The key to early identification of malrotation is to listen to the patient’s concerns regarding rotation. Typically, the patient will make it known that the functional or cosmetic aspects of a malrotated femur are unacceptable. The surgeon should perform an appropriate examination. A CT rotational profile will help in quantifying the degree of malrotation and in determining whether a corrective procedure is indicated. Despite its limitations, the CT rotational profile offers the best means of quantifying rotational asymmetry. Correction is easier to perform before fracture union, and this should be discussed.
with the patient. Following diagnosis of significant malrotation, the corrective procedure can be planned. A high potential for drill-hole cutout exists in the patient with correction measuring <20° in whom the previous distal locking site is to be used because of the proximity of the new interlock to the previous site of interlock placement.38 This may be an issue when correction is indicated in the early postoperative period before the bone has healed. Depending on the nail used, this risk can be overcome by using alternative locking holes or a dynamic locking slot. Alternatively, the nail could be advanced or retracted to avoid the previous site of locking.

Derotational osteotomy is used to correct malrotation after the fracture has healed. A CT rotational profile must be obtained to determine the degree of malrotation (Figure 4). Before performing the correction, two stout (3.8-mm) Steinmann pins are placed. One pin is placed in the trochanteric region, either in front of or behind the nail; the other is inserted into the distal femoral condylar region. The pins may be placed at an angle to each other, so that the two pins will be parallel once the correction is made (Figure 6). Alternatively, the pins may be placed parallel and used as a goniometer to measure the correction as it occurs. Stout Steinmann pins must be used because soft tissues will bend smaller Kirschner wires, thereby preventing an accurate guide to the needed correction.39,40

The nail is removed, and a transverse osteotomy is performed with an IM saw or an open technique with multiple drill perforations and an osteotome. Transverse osteotomy with an IM saw reduces the disruption of the periosteal blood supply and aids in bone healing.19 Following removal of the nail, the IM canal is reamed an additional 1.5 mm greater than the diameter of the saw.

On completion of the osteotomy, the correction is made, as measured using the Steinmann pins and a goniometer. A new IM nail is placed and statically locked, with attention paid to the proximity of the new distal interlocks to the previously placed screws (Figure 6). Using this technique, Navadgi et al41 achieved an average of 78% of the planned rotational correction in seven patients. Average residual deformity measured 5° (range, zero to 14°). An open technique with bone grafting is suggested in patients in whom mild shortening is also to be corrected.39
Summary

Malrotation is a common problem following IM nailing of femoral shaft fracture, and it may occur even with proper technique. Before leaving the operating room, the surgeon should assess the length and rotation of the injured extremity and perform a ligamentous examination of the ipsilateral knee after bumps, traction, and other positioning devices have been removed. If significant asymmetry is demonstrated, it can be managed appropriately before the patient leaves the operating room. During the early postoperative period, malrotation can be managed with revision of the reduction and exchange of the distal interlocks. Late diagnosis requires corrective osteotomy with revision nailing.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, reference 8 is a level I study. References 4, 9, 22, and 23 are level II studies. References 1, 2, 5, 6, and 16 are level III studies. References 7, 15, 18, 19, 27-29, and 36-40 are level IV studies. References 3, 10, 11-14, 20, 25, 26, 30, 31, 33-35, and 41 are level V expert opinion.

Citation numbers printed in bold indicate references published within the past 5 years.


