Multiple Radiographic Projections in Detecting Intra-articular Screw Penetration During Fixation of Femoral Neck Fractures

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abstract

Full article available online at Healio.com/Orthopedics

The authors performed a cadaveric study to evaluate the efficacy of multiple fluoroscopic projections in detecting intra-articular penetration of the screws during femoral neck fracture fixation and to determine the most suitable radiographic projection. Models of intra-articular penetration in 8 normal proximal femur specimens were created by placing the pins in different quadrants of the femoral head and extending 1 mm beyond the femoral head surface. The tip-to-surface distance was measured on anteroposterior (AP) and lateral views, with the femur positioned at varying degrees of rotation, flexion, adduction, and abduction. After correcting for differences in magnification, associations between the tip-to-surface distance and femur position were noted. In certain femur positions and K-wire placements, conventional AP and lateral views did not show that the wire extended beyond the surface of the femoral head. The tip-to-surface distance on an AP radiograph with the femur in the neutral position was not comparable to that on the lateral view with the femur positioned at 20° of adduction (P=.821). However, the tip-to-surface distance on an AP radiograph with the femur in the neutral position varied significantly (P<.001) from all other tip-to-surface distances on either the AP or lateral projection. A linear association was found between the tip-to-surface distance and femur rotation angles on AP views and between femur adduction and abduction angles on lateral views. In conclusion, fluoroscopy in varied projections at different angles can detect unrecognized intra-articular screw penetration during internal fixation of femoral neck fracture. Additional special projection methods are suggested to identify and prevent intra-articular screw penetration.

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Received: December 17, 2013; Accepted: February 20, 2014; Posted: October 8, 2014. doi: 10.3928/01477447-20140924-54

Figure: Measurement of the K-wire tip-to-surface distance on the femoral head. Line BC (black arrow) represents a tip-to-surface distance of positive value. Point A shows the center of the circle superimposed over the femoral head, and point B shows the tip of the K-pin. Line AB extends to cut through the circle on point C.
Intracapsular femoral neck fractures are most frequently the result of high-energy trauma in young patients and account for approximately 3% of hip fractures.\textsuperscript{1,2} For young patients, the standard method of care is to salvage the head by performing closed reduction and internal fixation with cannulated screws,\textsuperscript{3-5} usually 3 cannulated cancellous screws. The technique has shown consistently good results, with advantages over other methods that include its minimally invasive nature and early rehabilitation of the patient.\textsuperscript{6-8} The clinical and biomechanical results are affected by time to fixation, anatomic reduction, screw placement, and various other factors. The length of the screw is considered an important factor in determining the stability and maintenance of reduction.\textsuperscript{9,11} However, the ideal screw length in the femoral head remains controversial.

Brown and Court-Brown\textsuperscript{9} observed an increased failure rate for suboptimally placed screws, especially if the tip of the screw was more than 12 mm from the subchondral articular surface. Another biomechanical study found that adequate screw length might enhance the holding power when the screws are inserted close to the subchondral bone.\textsuperscript{12} One of the most accepted methods for determining screw length is calculation of the screw tip-to-femoral apex distance.\textsuperscript{13,14} This distance is defined as the sum of the distance of the screw from the subchondral bone in both anteroposterior (AP) and lateral projections. A value of less than 25 mm is considered optimal for stability and maintenance of reduction.

Although a short screw tip-to-femoral apex distance is recommended, trying to place the screw very close to the subchondral surface increases the chance of inadvertent screw penetration into the joint. Unrecognized intra-articular penetration may interfere with vascularization of the subchondral bone and lead to necrosis.\textsuperscript{15} In addition, articular disruption subjects the subchondral bone of the femoral head to the pressure of a hemarthrosis, which is a potential risk factor for osteonecrosis.\textsuperscript{16,17} Therefore, the current accepted technique involves placing the screws as close as possible to the subchondral bone, taking care to avoid having the screw enter the joint.

During fixation of femoral neck fractures, in most cases, intraoperative fluoroscopy is used to assist in reduction and for intraoperative confirmation of screw length and placement. Because of the more or less spherical configuration of the femoral head, intra-articular penetration is difficult to determine accurately on conventional AP and frog-leg lateral radiographs.\textsuperscript{10,11} Noordeen et al\textsuperscript{11} found that the pin could actually be located outside of the femoral head (with an incidence of 8%) if it appeared outside the central two-thirds of the head on both AP and lateral views. Another study suggested several measurement methods to determine the actual screw position.\textsuperscript{18} However, these studies were based only on conventional radiographs. To the best of the authors’ knowledge, no reported studies have compared various radiographic projections for detecting inadvertent screw penetration into the hip joint during such surgeries.

In view of the paucity of data, the authors performed a cadaveric study to evaluate various radiographic projections for detecting inadvertent screw penetration. The authors also investigated radiographic guidelines for minimizing postoperative complications and reducing unnecessary radiation exposure to both patient and staff during fluoroscopy.

**Materials and Methods**

Eight embalmed proximal femurs with intact cartilage from adult cadavers (6 male and 2 female) were obtained from the anatomic laboratory at Wenzhou Medical College. The specimens were examined in detail and had no abnormalities, such as osteophytes or chondral lesions on the femoral head. The average age of the cadavers at the time of death was 51.6 years (range, 38-73 years). With reference to the anterior-posterior axis of the femoral neck, the femoral head was divided into 4 zones according to the transverse and vertical cross-sections (Figure 1): anterosuperior, anteroinferior, posteroinferior, and postero-inferior. Femoral head diameter, neck shaft angle, and femoral anteversion angle were measured on each specimen.

Using the common starting point and an anterior cruciate ligament guide (Smith & Nephew, Andover, Massachusetts), under direct visualization, a 2.0-mm Kirschner wire (Synthes, Solothurn, Switzerland) was driven into each of the

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**Figure 1:** The femoral head was divided according to the axis of the femoral neck on both anteroposterior (AP) and lateral views (A). Four zones were created with reference to the anterior-posterior and superior-inferior axes: anterosuperior (AS), anteroinferior (AI), posterosuperior (PS), and posteroinferior (PI) (B).
4 zones of the 8 femoral heads. To make each specimen a model of intra-articular perforation, pins were placed to extend 1 mm beyond the articular surface (Figure 2). The pin position was then recorded fluoroscopically.

All radiographs were obtained by an independent experienced radiologist (S.C.), using a Philips DR system (Philips, Cleveland, Ohio). First, a standard AP radiograph was taken in the neutral position with the proximal femur rotated internally 15° to 20° from the vertical position. This position allowed alignment of the femoral neck parallel to the image receptor and could best establish the angle of the femoral neck. Another 4 AP radiographs were obtained subsequently by angling the fluoroscopic beam to 20° of internal rotation, 20° of external rotation, 40° of internal rotation, and 40° of external rotation.

With the arm held in a neutral position, the beam was adjusted 30° and then 60° caudal to obtain the remaining 2 AP radiographs. Moreover, 5 lateral views were obtained by moving the femur, which was subsequently fixed on a radiolucent table. These 5 lateral positions were the neutral lateral view, lateral views with 20° or 40° of abduction, and lateral views with 20° or 40° of adduction. For the neutral lateral view, the central beam was directed horizontally toward the proximal femur with approximately 20° of cephalic tilt. The cassette was placed against the lateral aspect, with the femur held in 15° to 20° of internal rotation. Each fluoroscopic radiograph was transmitted to the picture archiving and communication system.

Radiologic measurements of each image were performed on the picture archiving and communication system 6 different times by 5 independent physicians (G.L., G.Y., E.P.G.-A., M.L., Z.P.) who did not participate during pin insertion. In particular, the tip-to-surface distance was defined as the shortest distance from the tip of the K-wire to the surface of the femoral head (Figure 3). The tip-to-surface distance was calculated and recorded for both AP and lateral views. First, a circle was superimposed over the globular femoral head. A line was then drawn from the center of the circle to the tip of the K-wire and extending to the outside of the circle. The tip-to-surface distance was defined as the distance from the tip to the intersection of the line and the circle.

To obtain the true tip-to-surface distance, corrections were made for magnification using the known diameter of the K-wire as reference (Figure 4), where \( d_a \) is the true diameter of the K-wire (2 mm), \( d_m \) is the diameter of the K-wire measured on the picture archiving and communication system, and \( TSD_m \) is the tip-to-surface distance measured on the picture archiving and communication system. A negative tip-to-surface distance value indicated that the tip of the K-wire was located beyond the articular surface, whereas a positive value meant that the tip was located entirely within the femoral head. Finally, the mean tip-to-surface distance value was calculated.

For statistical analyses the authors used the Statistical Package for the Social Sciences (SPSS) software for Windows (version 11.5; SPSS, Chicago, Illinois). An independent samples \( t \) test was performed to analyze differences in tip-to-surface distance between the neutral position and other positions on AP and lateral views. The \( P \) value was set at a significance level of .05.

**RESULTS**

The mean dimensions of the femoral heads, neck shaft angles, and femoral anteversion angles were within the
normal limits for the healthy Chinese population. Specifically, the average maximum diameter of the femoral head was 45.6±2.1 mm (range, 42-48 mm), and the minimum was 45.0±2.1 mm (range, 42-47 mm). The mean neck shaft angle was 127.5°±2.6° (range, 123°-131°), and the mean femoral anteversion angle was 12.0°±1.7° (range, 10°-15°).

With the K-wire inserted through the anteroinferior, posterosuperior, or posteroinferior zone, the authors compared tip-to-surface distances between each position of the femur and that of the neutral position in both AP and lateral views. They found a high likelihood that intrarticular pin penetration in the anteroinferior, posterosuperior, and posteroinferior zones could be missed in both conventional AP (Figure 5) and lateral views. In the AP view, when the tip of the guide pin was located in the anterosuperior zone, there was a significant difference in tip-to-surface distance between femurs in the neutral position and those in the tested internal and external rotation positions (P<.001; Table 1). Likewise, the AP view showed a significant difference in tip-to-surface distance measured at 30°, 60°, and 90° of flexion (ie, neutral lateral view) and that seen in the neutral position (P<.001; Table 2). On lateral views, statistical differences were observed in tip-to-surface distance between

<table>
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<th>Zone</th>
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<th>Internal Rotation*</th>
<th>External Rotation*</th>
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<td>10.00±0.02</td>
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*P<.001, all compared with the neutral position.

Table 2

<table>
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<td>Posteroinferior, mm</td>
<td>0.00±0.01</td>
<td>-2.01±0.02</td>
<td>0.00±0.02</td>
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*P<.001, all compared with the neutral position.
femurs in the neutral position and those in 40° of adduction and 20° and 40° of abduction ($P<.001$). However, mean tip-to-surface distance was similar in femurs in the neutral position and those in 20° of adduction ($P=.821$; Table 3).

In AP views, with the K-wire in the anterosuperior or anteroinferior zone, a positive linear correlation was found between mean tip-to-surface distance and degree of internal or external rotation angles, whereas a negative linear correlation was observed with K-wires in the posterosuperior or posteroinferior zones (Figure 6A). However, in AP views, there was no significant association between mean tip-to-surface distance and flexion angle with the K-wire in any zone (Figure 6B). On lateral views, with the K-wire in the anteroinferior or posteroinferior zone, a positive linear correlation was found between mean tip-to-surface distance and adduction or abduction angle, but the correlation was negative with K-wires in the anterosuperior and posterosuperior zones (Figure 6C).

**DISCUSSION**

Various studies have proven that the biomechanical properties of long screws are superior for fixation of femoral neck fractures in young patients. However, iatrogenic intra-articular penetration as a result of excessively long screws may lead to disastrous complications, including chondral damage, osteonecrosis, and finally pain and functional disability. Intraoperative AP and lateral fluoroscopy are conventionally used to confirm screw positions in the femoral head, and it is commonly believed that placement of a screw in the central third of the head, as observed on both radiographs, is ideal. Nevertheless, several studies have shown evidence of penetration into the hip joint that was not noticed during surgery.

Hernigou and Besnard assessed intraoperative radiographs of 30 patients with femoral neck fractures and found that previously unrecognized screw penetration had occurred in 20% of patients. In half of these, penetration was visualized

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<th>Adduction*</th>
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<td>Anterosuperior, mm</td>
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<tr>
<td>Anteroinferior, mm</td>
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* $P<.001$, all compared with the neutral position unless noted otherwise.
† $P=.821$. 

**Figure 6:** Tip-to-surface distance (TSD) with the femur placed in different positions on anteroposterior (AP) (A and B) and lateral views (C). Abbreviations: AB, abduction; AD, adduction; AI, anteroinferior; AS, anterosuperior; ER, external rotation; FL, flexion; IR, internal rotation; PI, posteroinferior; PS, posterosuperior.
Figure 7: Ideal hip positions recommended for the detection of unrecognized penetration in 4 zones of the femoral head based on anteroposterior (AP) and lateral (LT) views. Abbreviations: AB, abduction; AD, adduction; AI, anteroinferior; AS, anterosuperior; ER, external rotation; IR, internal rotation; PI, posteroinferior; PS, posterosuperior.

at the posterior part of the femoral neck. The authors showed a similar result in the current cadaveric study. Specifically, a K-wire extending 1 mm beyond the surface from any of several zones of the femoral head, especially the anteroinferior zone, could falsly appear to be located entirely within the femoral head on both conventional AP and lateral radiographs. The authors suggest that multiple radiographic projections are necessary during surgery to avoid iatrogenic penetration, although this might increase radiation exposure time for both staff and patients.

This study investigated whether and how much penetration could be detected from various radiographic projection directions, with the goal finally to determine radiographic guidelines to reduce the incidence of osteonecrosis and radiation dose. They likened the femoral head to a mathematical model of a sphere, and then, with the femur in various positions, the authors measured the tip-to-surface distance, that is, the shortest distance from the tip of the inserted K-wire to the femoral head surface, from radiographic images taken from several directions.

The tip-to-surface distance was used in this study as an optimal index for evaluation of the risk of penetration of the wire beyond the surface of the femoral head. The tip-to-surface distance is not the same as the screw tip-to-femoral apex distance suggested by Baumgaertner et al.13 and Baumgaertner and Solberg.14 Baumgaertner et al.13 conducted a retrospective investigation of 193 patients with peritrochanteric fractures and concluded that the screw tip-to-femoral apex distance was a strong predictor of cutout of the lag screw. Other authors who had similar experiences accepted these findings, and the screw tip-to-femoral apex distance is now the standard for determining optimal screw position.20-22 However, despite reliance on the screw tip-to-femoral apex distance, cutout of the screws in proximal femoral fractures has been frequently observed on the weight-bearing area of the femoral head.15,20,23 During fixation of femoral neck fracture, the screw is inserted along the pin orientation and might theoretically breach into any part of the surface on the femoral head. Because the current study investigated intra-articular penetration rather than fixation failure or screw cutout per se, the authors considered tip-to-surface distance an ideal parameter to illustrate the severity of penetration.

The current study showed a linear association between apparent tip-to-surface distance and hip rotation angles on AP views and adduction and abduction angles on lateral views. For instance, when the tip of the K-wire was placed in the anterosuperior zone of the femoral head, tip-to-surface distance linearly increased with femur positions from internal rotation to external rotation. The minimal tip-to-surface distance was observed on the AP radiograph with the femur in maximum internal rotation. Likewise, the minimum tip-to-surface distance could also be found when adduction was obtained on lateral views. Hence, the authors proposed to perform additional fluoroscopy in both positions after the site of the tip of the K-wire was confirmed in the anterosuperior zone (Figure 7). According to the findings, the ideal projection positions for the K-wire driven into the other zones are shown in Figure 7. These results are inconsistent with the conclusions of Kumar et al.22 who considered that the screw could not be located in the joint if a hip screw placed anteriorly was found breaching the articular surface in internal rotation. The current authors doubted these suggestions because Kumar et al.22 did not create further zones for the anteriorly located screws.

In the current study, in the lateral view, tip-to-surface distances measured in the anterosuperior zone and the anteroinferior zone had an inverse linear association. Whether the screw was inserted into the anteroinferior or anterosuperior zone of the femoral head, the tip of the screw might falsely appear to be located entirely within the femoral head on AP views of the internally rotated femur. Nevertheless, penetration of the screw placed in the anteroinferior zone could be detected on lateral views with the femur in abduction. This difference could be identified only when the screw was located in the anterosuperior zone; the authors visualized penetration on lateral views only when the femur was placed in adduction. Consequently, initially, the superior or inferior part of the femoral head should be individually distinguished to exclude intra-articular penetration before additional adduction or abduction is used for lateral projection of an anteriorly placed screw.

Based on the current findings, the authors believe that specific projections are required to accurately determine the position of the guide pin or K-wire, and depending on the intended screw position, this may vary. Radiographs obtained in AP and lateral views with the femur in the neutral position should be obtained first to confirm the exact location of the tip of the guide pin. Subsequently, according to the location of the pin on these views, the recommended projection angles should be adjusted by changing the position of the femur or the fluoroscopic beam (Figure 7). This method could provide a guideline
for fixation of femoral neck fractures, especially for junior orthopedic surgeons. This method has the potential to shorten surgical time, decrease exposure to fluoroscopy, and possibly reduce the incidence of osteonecrosis as a result of inadvertent screw penetration.

The current study was limited in that the subjects consisted only of cadavers with a normal neck shaft angle and no fracture lines. In surgical practice, the quality of fracture reduction and the ensuing neck shaft angle might influence measurement results intraoperatively. Valgus or varus malreduction of the fracture affects the tip-to-surface distance. Therefore, in future studies, more cadavers with coxa valga and coxa vara malformations should be included. Another consideration is that the authors did not simulate an actual surgical environment or positioning because whole-body cadavers were not used, but only the hip joint with the limb. However, the authors believe that determination of a definite linear association between projection angle and tip-to-surface distance was not significantly affected by this factor because the distance gradually increases or decreases linearly with a change in femur position. In addition, calculation of the tip-to-surface distance depended on likeness of the femoral head to a simple regular sphere. Perhaps this led to measurement errors of the tip-to-surface distance because the true configuration is affected by the fovea of the femoral head and variable chondral thicknesses in the different zones. Finally, some recommended projection methods cannot be easily obtained during intraoperative fluoroscopy, especially on a fracture table. However, the lower extremity or the fluoroscopic beam should be moved to the maximum possible angle because tip-to-surface distance showed a linear trend as the position changed.

**Conclusions**

Conventional AP and lateral fluoroscopy may not always show screw placement accurately and may sometimes miss inadvertent screw penetration into the hip joint. This study recommends that additional projection directions should be obtained, depending on screw positioning, for a clearer and more accurate assessment of the distance between the screw tip and the femoral head surface, that is, the tip-to-surface distance. The authors believe that the findings from this study will decrease surgical time, will reduce fluoroscopic exposure of operating room staff, and may reduce the incidence of osteonecrosis of the femoral head that occurs secondary to screw penetration.

**References**


