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Accidental external rotation of distal interlock jig in retrograde femoral nailing can lead to more prominent screws

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ABSTRACT

Objective: Symptomatic distal interlocking screws in retrograde femoral nailing are common due the difficulties of imaging the trapezoidal femur. Screws appearing to have appropriate length on imaging may possibly be prominent, creating symptoms. Screw trajectory may influence the degree of this radiographic error. We hypothesize that external rotation of screw trajectory will increase measurement error of screw length.
Design: Retrospective.
Setting: Urban Level I Tertiary Trauma Center.
Participants: 283 patients with Computer Tomography (CT) scans of the native knee were retrospectively identified. Simulation was done of the trajectory of an interlock at 20 mm and 40 mm proximal to the nail entry point, which represent common screw positions associated/not associated respectively, with removal. The distance between the radiographic medial cortex and the tip of the transverse screw was calculated (D). The angle (Ψ) between the transverse trajectory and a modified trajectory aimed at the most medial cortex to avoid radiographic measurement error was calculated. Geometric modeling was utilized to calculate the measurement error (D) in the event of accidental external rotation. The angle of the medial slope was also measured (Θ).
Intervention: Review of CT imaging of normal distal femora.
Main Outcome Measurements: CT measurements of distal femora.
Results: The mean distance (D) at 20/40 mm was 4.21 [95%CI 4.02–4.402] and 2.03 mm [95%CI 1.78–2.83], respectively ($p < 0.0001$). The mean angle (Ψ) between the transverse and modified trajectory at 20/40 mm was 12° [95%CI 11.5–12.5] and 9.60° [95%CI 9–10.2], respectively ($p < 0.0001$). External rotation by a similar amount nearly triples the measured difference (D). The measured medial slope was significantly increased as screws were placed more proximal ($\Theta_{20\ mm}$ 46.5 vs $\Theta_{40\ mm}$: 48.7°, $p < 0.00001$).
Conclusion: The distance between the perceived medial cortex and the tip of the most transverse screw is 4.21 mm and could account for painfully prominent screws. In more proximal screws this distance is decreased. Internal rotation of the screw trajectory 12° can reduce this distance (D), which has implications in nail design. External rotation, amplifies this difference nearly three-fold. Surgeons should avoid external rotation of the aiming arm to prevent prominent screws.

Introduction

Femoral shaft fractures occur frequently. Depending on the country of origin, its incidence of occurrence ranges from 9.5 to 18.9 per 100,000 annually [1]. Knee pain is common with retrograde nailing of the femur, with its incidence has been reported to be as high as 60% [2–5].

The etiology of anterior knee pain after retrograde intramedullary nail placement is multi-factorial, including but not limited to nail impingement, potential nerve injury, and soft tissue irritation secondary to screw protrusion [6–8]. Protrusion of the distal interlocking screws is a frequent, but potentially preventable, cause of knee pain [6]. Although manufacturers recommend the use of calibrated drill bits and/or depth measurement, these measurements are subject to error based on anatomical variation, soft tissue interposition, etc. [9]. Thus, fluoroscopy is often utilized to confirm measurements and final screw placement.

The trapezoidal shape of the distal femur, with the anterior surface being narrower than the posterior surface, makes

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intraoperative imaging difficult. Thus, as a result of this shape, screws that appear flush with the medial cortex on conventional posterior-anterior intraoperative imaging may in fact be prominent. It is unknown how much this phenomenon contributes to measurement error or if nail rotation and changes in implant design can help alleviate this problem.

This study focuses on quantifying the degree of radiographic measurement error in distal locking screws used in retrograde nailing of the femur. Additional aims of the study included determining if altering the screw/interlock trajectory can modify this effect. Expected results of this study include less radiographic error the further from the joint the screw is placed and that external rotation of the screw trajectory will significantly increase this error. This can hopefully guide surgeons in the prevention of prominent hardware by emphasizing elements of distal interlock placement technique.

Method

Patient cohort

After institutional review board approval, trauma patients admitted to our level 1 trauma center from 2015 to 2017 with routine standardized lower extremity computer tomography (CT) examinations for ipsilateral tibial plateau fractures were identified retrospectively. These patients were chosen as they were likely to have normal distal femur anatomy (e.g. atraumatic). Patients were excluded if their CT scan was not performed at our center, had ipsilateral distal femur fractures, had prior history of trauma, pathologic lesions, hypoplastic lateral condyle or had CT scans with axial slices greater than 2 mm.

Evaluation of CT studies

Routine axial CT images were analyzed in bone windows utilizing a standard DICOM viewer (McKesson, San Francisco, CA, USA). Sagittal and coronal reconstructions were utilized to identify the start point as per manufacturer guidelines on the axial images. Using this start point, the trajectory of the femoral nail was traced on this reconstruction along the anatomic axis of the femur; this allowed appreciation of the center of the femoral nail along the axial images. After the center of the femoral nail had been identified, measurements were performed on the axial imaging. The two sets of measurements were based on common manufacturer locations of distal interlocking screws with an added 5-mm margin to account for recessing of the femoral nail at the joint line. Measurements were performed a total of four times (twice at two separate time points) and averaged for analysis. The measurements (shown in Fig. 1) included a representation a transverse screw trajectory placed parallel to the intercondylar axis and through the center of a theoretically placed retrograde nail (X), a line parallel to X at a plane that aligns with the medial most point of the medial cortex (Y), and the anterior to posterior distance (Z) between X and Y. Additional measurement (Θ) was the angle between the slope of the medial femoral condyle (determined be creating a best fit line along this cortex) and the intercondylar axis.

Calculations and statistical analysis

The difference (D) in the measurements of X and Y in the coronal plane was calculated and represents the potential radiographic measurement error between the theoretical radiographic medial cortex, as seen on AP radiographs, and the location of the tip of a transverse interlocking screw placed flush with the medial cortex (Fig. 2). Classic geometric principles were used to calculate Ψ, which represents the theoretical angle at which screw trajectory can be internally rotated to "target" the medial most cortex. Inverse tangent (Tan^{-1} ($\frac{Z}{Y}$)) was used to quantify this angle (Fig. 2). Geometric modeling utilizing the above calculations was utilized to predict the change in measurement error if the screw trajectory was accidently externally rotated 10° (Fig. 3).

Standard descriptive statistics were utilized to describe our findings. A paired *t*-test was utilized to assess the difference between distal and proximal measurements.

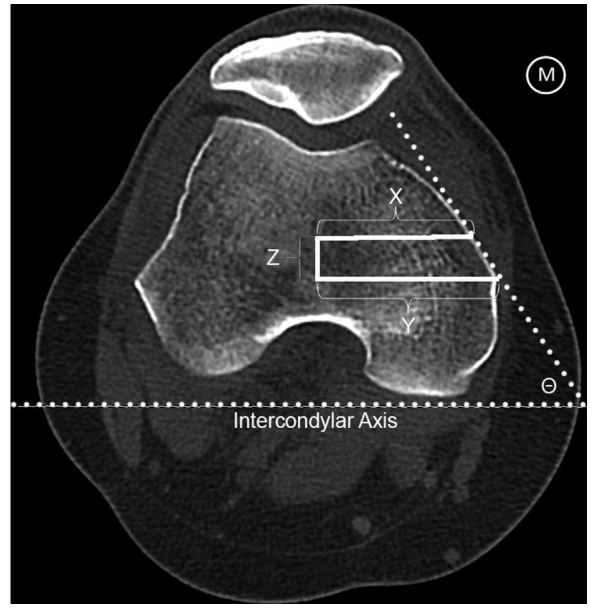

Fig. 1. Axial view of the distal femur displayed in bone window. X represents the standard transverse screw trajectory from center of the femur. Y represents medial most point of the medial cortex parallel to the line X. Z represents the anterior to posterior distance between X and Y. The slope of the medial femoral condyle (Θ) was measured by creating a best-fit line along the medial cortex intersecting the superimposed intercondylar axis.

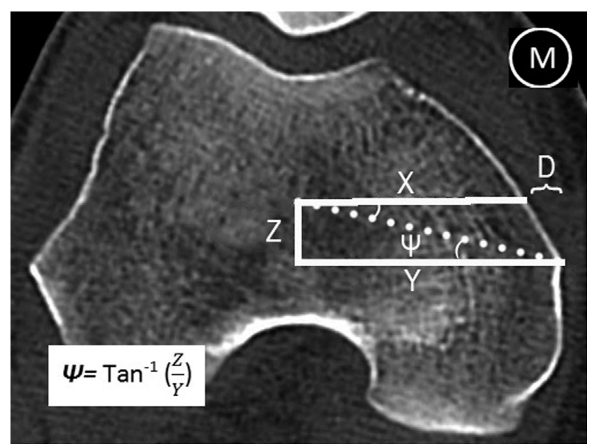

Fig. 2. Geometric principles were used to calculate Ψ (Tan^{-1} ($\frac{Z}{Y}$)), which represents the theoretical angle the screw trajectory can be internally rotated to "target" the medial most cortex.

Results

A total of 283 patients were identified retrospectively, of which, 200 met inclusion/exclusion criteria. On average, $X_{20\text{ mm}}$ (traditional screw path, distance from center to medial cortex) was 36.9-

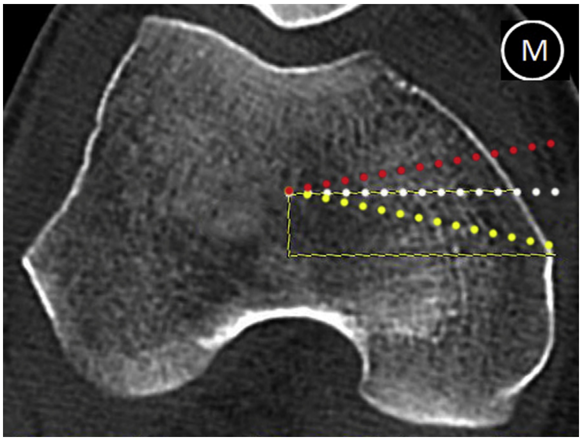

Fig. 3. Visual representation of how internal and external rotation of screw trajectory effect screw prominence with screws of identical size. All three dotted lines are the same length. The red line (anterior) represents external rotation of the trajectory by 10°, the white line represents standard transverse screw trajectory, and the yellow line (posterior) represents internal rotation towards the most medial aspect of the femur (12°). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

mm (Std Error, 0.24; CI 95% 36.4–37.4), $Y_{20\ mm}$ was 41.1-mm (Std Error 0.25; 95% CI, 40.6–41.6), $Z_{20\ mm}$, was 8.71-mm (Std error, 0.20, 95% CI 8.31–9.10). The average calculated value of $D_{20\ mm}$ (length of line X- length of line Y) representing the theoretical measurement error was 4.21-mm (Std Error 0.10, 95% CI 4.02–4.40). The average measured medial slope ($\Theta_{20\ mm}$) was 46.5 ° (Std error, 0.35; 95% CI 45.78–47.17). The average calculated angle $\Psi_{20\ mm}$ was 11.99 ° (Std error, 0.26; 95% CI 11.46–12.51) (Table 1).

On average, $X_{40\ mm}$ (transverse screw path) was 27.7-mm (Std Error, 0.25; CI 95% 27.2–28.2), $Y_{40\ mm}$ was 30.0-mm (Std Error 0.31; 95% CI, 29.1–30.1), and $Z_{40\ mm}$ was 5.12-mm (Std error, 0.18, 95% CI 4.77–5.48). The average calculated value of $D_{40\ mm}$ (length of line X- length of line Y) representing the theoretical measurement error was 2.03-mm (Std Error 0.12, 95% CI 1.78–2.28). The average measured medial slope ($\Theta_{40\ mm}$) was 48.7 ° (Std error, 0.45; 95% CI 47.8–49.6). The average calculated angle $\Psi_{40\ mm}$ was 9.60 degrees (Std error, 0.30; 95% CI 9.01–10.18) (Table 1).

Paired comparison of the measurements between the two locations demonstrated a significantly decreased margin for radiographic measurement error as screws are placed more proximal (4.21-mm vs 2.03-mm, $p < 0.00001$). Likewise, the measured medial slope was significantly increased as screws are placed more proximal (46.5 vs 48.7 °, $p < 0.00001$). Changing screw trajectory to “target” the medial most cortex was 11.99 versus 9.60 ° ($p < 0.00001$) at the distal and more proximal screw locations, respectively.

Geometric modeling (GM) with screw trajectory externally rotated 10 ° determined D_{GM} (length of line X- length of line Y) to be 12.5-mm, nearly three times the amount with standard trajectory.

Discussion

Despite prominent screws being a known pain generator leading to surgery for hardware removal, there is little evidence to guide surgeons on how to prevent this complication, other than emphasizing good surgical technique.[7] The use of traditional intraoperative PA fluoroscopy to confirm measurements and final screw placement lacks precision since the image displayed is a projection of the 3-dimensional, trapezoidal shape of the distal femur (Fig. 4). When performing standard PA fluoroscopy, the anterior surface of the distal femur is superimposed on the posterior surface and the screw tip and screw head is in the shadow of posterior condyles on the standard PA radiograph [9]. This leaves room for measurement error as the radiographic medial cortex is more medial than the true medial cortex which screws penetrate. This study looked to address how the intraoperative radiographic evaluation of screw length can play into the placement of prominent screws and by utilizing CT scans of intact femora, was able to demonstrate that the margin of error with radiographic measurement is 4.21-mm and 2.03-mm at two common distal interlock locations (20 and 40-mm, respectively). Although the threshold of how prominent a screw must be to be symptomatic is unknown, this study demonstrates how screws that are perceived to be either flush or just past the medial cortex are in fact, at least 4.21-mm too long. Additionally, external rotation of the screw trajectory was shown to increase the length of protruding screw.

This study is the first to the authors' knowledge, to attempt to quantify this margin of error. Previous studies by Hamaker et al. demonstrated that screws placed less than 40-mm from the joint line (represented by the most distal screw in this study) were associated with increased rates of hardware removal and also a higher risk of symptomatic hardware if the distal interlocking screws appear to be prominent on AP radiographs [10]. This study complements the research done by Hamaker et al. by giving an anatomic and radiographic basis for why placement of screws more distal may lead to greater symptoms, which is quite common [11]. As screws are placed more proximal however, this difference in measurement error is significantly decreased, and may offer explanation as to why these screws are less likely to be removed.

Given the trapezoidal shape of the distal femur, we sought to determine if modifying the screw trajectory could influence this measurement error. By “targeting” the medial most cortex theoretically, radiographic measurement error could be decreased. We demonstrated that internal rotation of the screw trajectory by 12 ° at the distal most interlock could decrease this error. Although this is an interesting finding and has implications in nail design, we do not advocate for the routine internal rotation of retrograde nails to take advantage of this finding, as this could risk difficult screw placement of proximal A-P interlocking screws. Our geometric model demonstrates that external rotation 10 ° magnifies the measurement error by nearly three times. This was based on proper placement of the nail according to manufacturer guidelines. Placement of the starting point more posteriorly would result in

Table 1
Measurements performed at 20 mm and 40 mm proximal to the Blumensaat's line.

	20 mm (Mean, Std Error, 95% CI)	40 mm (Mean, Std Error, 95% CI)	P
X	36.9 mm (0.24; CI 95% 36.4 – 37.4)	27.7 mm (Std Error, 0.25; CI 95% 27.2 – 28.2)	
Y	41.1 mm (0.25; 95% CI, 40.6 – 41.6)	30.0 mm (Std Error 0.31; 95% CI, 29.1 – 30.1)	
Z	8.71 mm (0.20, 95% CI 8.31 – 9.10)	5.12 mm (Std error, 0.18, 95% CI 4.77 – 5.48)	
D	4.21 mm (0.10, 95% CI 4.02 – 4.40)	2.03 mm (Std Error 0.12, 95% CI 1.78 – 2.28)	< 0.00001
Θ	46.5 degrees (0.35; 95% CI 45.78 – 47.17)	48.7 degrees (Std error, 0.45; 95% CI 47.8 – 49.6)	< 0.00001
Ψ	11.99 degrees (0.26; 95% CI 11.46 – 12.51)	9.60 degrees (Std error, 0.30; 95% CI 9.01 – 10.18)	< 0.00001

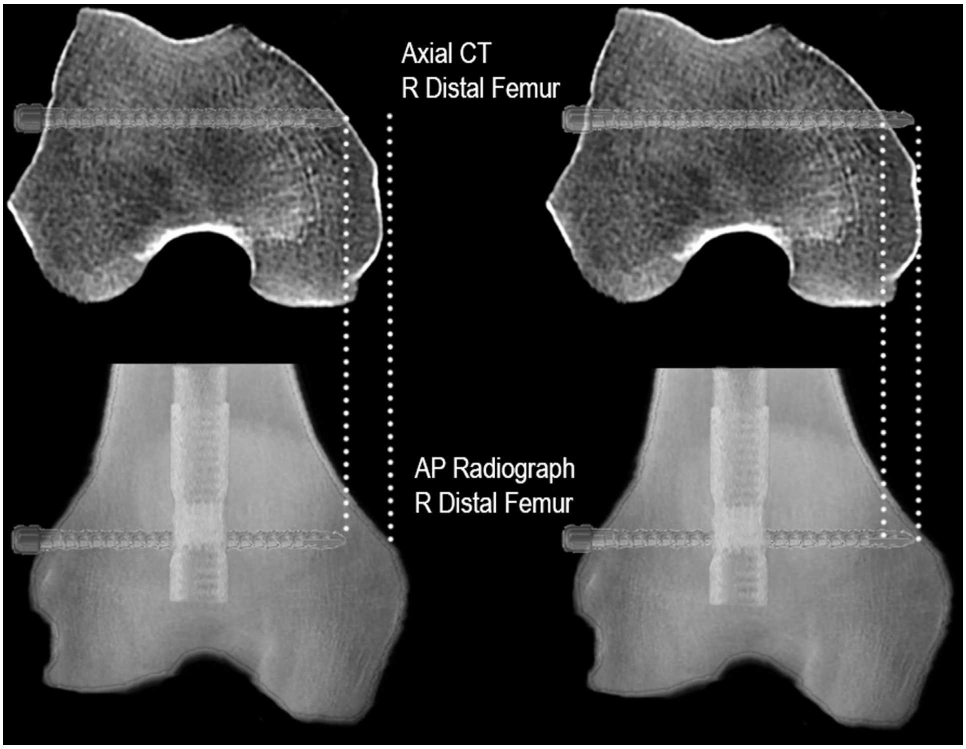

Fig. 4. Illustrations of theoretically placed screws and perceived medial cortex versus actual medial cortex.

less measurement error, and likewise, anterior placement would make this effect more pronounced.

The present study shows that the medial femoral slope is 46.48° relative to the intercondylar axis at the most distal interlock locations. The present finding is consistent with the previous reports by Zheng et al., whom demonstrated that the medial distal femur tangential view can be obtained by adjusting the direction of the X-ray beam of 40.68° from the sagittal plane to parallel the medial surface of the distal femur [9]. The clinical utility of this view to determine prominent screws is unknown.

The strengths of our study include our large sample size and all measurements were performed via a calibrated CT scanner. As a result, the measurements for the present study remain consistent and less measurement bias is introduced. The small range of confidence intervals accurately reflects the consistency of our results. In addition, the findings and calculations from the present study are derived from a simple geometric calculation. Given that prevention of this error (i.e. prevent external rotation of the jig) is easy to perform, this suggests that the technique is widely adoptable with minimal effort.

The present study is subject to several limitations. We described a technique of measurement that uses theoretical calculations to generalize the trauma patient population. We recognize that each patient possesses unique anatomical details and requires individualized treatment options. Likewise, our study does not take into account for magnification experienced during fluoroscopic imaging, which may influence perceived differences in screw lengths. However, this study is meant to be a proof-of-concept study, and future clinical studies to validate the clinical utility of our proposed concept are necessary. Further, this study does not account for beam divergence from a PA direction. This is highly variable, as it depends on the nonstandard distance of the distal femur to the radiation source of the fluoroscope. This would mean that our measurements could actually underestimate the clinical problem.

At our institution, we instruct our residents to pay close attention to the positioning of the patella (e.g. facing anteriorly) and ensure that the jig is parallel to the floor, as accidental external rotation, which is easily accomplished through gravity, can worsen the effect described in this manuscript. Although beyond the scope of this manuscript, we also advocate for the use of femoral notch view to help rule out prominent distal screws which may appear flush on PA imaging, as the femoral notch provides a more en face view of the medial cortex.

In conclusion, the findings of the present study demonstrate that the anatomy of the distal femur is complex, and that while screws may appear flush with the medial cortex on AP imaging, they may in fact be prominent, which is worsened by more distal placement of interlocks and accidental external rotation of the interlock aiming arm. Surgeons should be mindful of this effect when placing distal interlocks, and be sure to avoid accidental external rotation of the jig. Careful adherence to these principles can help prevent painful prominent screws which can hopefully decrease the need for secondary hardware removal.

Conflict of interest statement

Boshen Liu, MD and Shea Comadoll, BS have nothing to disclose. Joseph Hsu, MD was a paid presented/speaker for Smith and Nephew. He is also a board or committee member of the Limb Lengthening Research Society. The terms of these arrangements have been reviewed and approved by Carolinas Medical Center in accordance with its policy on objectivity in research. Paul Matuszewski, MD receives research support from Stryker. The terms of this arrangement have been reviewed and approved by the University of Kentucky in accordance with its policy on objectivity in research.

Disclosures

List of disclosures can also be found on the AAOS website: http://www7.aaos.org/education/disclosure/search.

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