Intraoperative determination of the risky angles and safe distances for preventing deep femoral artery injury during proximal femoral nailing for hip fractures in Asian people

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ABSTRACT

Objective: During proximal femoral nailing, deep femoral artery injury, a rare condition, is often missed and found late, leading to intractable complications such as false aneurysm, hematoma, and anemia. We aimed to determine the novel indicators of the high-risk vertical range and axial angle for deep femoral artery injury that can be easily confirmed intraoperatively using fluoroscopy for hip fracture.

Methods: In a single hospital, the lower extremity computed tomography angiographies of 88 patients (50 men and 38 women) were analyzed. A reference plane was defined as the femoral neck and shaft on the same straight line in the lateral view. Reference points were the lower end of the lesser trochanter and distal femur at 140 mm from the tip of the greater trochanter. To determine the high-risk angle for deep femoral artery injury based on the reference plane, the angle from the reference plane to the deep femoral artery (bone–arterial angle) and the shortest distance between the surfaces of the femur and the deep femoral artery (bone–artery distance) were measured at the lesser trochanter and the greater trochanter. We analyzed the bone–arterial angle and bone–artery distance values, their differences among the sexes, and their correlation with body height and body weight.

Results: Overall, in the lesser trochanter, the mean bone–arterial angle and bone–artery distance were 19.2° ± 8.0° and 22.9 ± 4.7 mm, respectively. In the greater trochanter, the mean bone–arterial angle and bone–artery distance were -13.9° ± 17.0° and 11.3 ± 4.1 mm, respectively. The mean bone–artery distance of the lesser trochanter was significantly longer in men than in women (24.1 ± 4.5 mm and 21.4 ± 4.5 mm, respectively, P < 0.001), and for the lesser trochanter, positive correlations were found between body height and both bone–arterial angle and bone–artery distance (r = 0.373, P < 0.001; and r = 0.456, P < 0.0001, respectively), with body weight and bone–artery distance positively correlated (r = 0.367, P < 0.001). At the greater trochanter, there were negative correlations between body height and bone–arterial angle (r = -0.3671, P < 0.0001) and weight, and bone–arterial angle (r = -0.338, P < 0.01).

Conclusion: The knowledge of our reference plane and high-risk angles and distances allows surgeons to minimize the risk of deep femoral artery injury. These are easily confirmed intraoperatively using fluoroscopy, allowing surgeons to avoid maneuvering in the deep femoral artery range.

Level of Evidence: Level IV, Diagnostic Study

Introduction

Although deep femoral artery (DFA) injury is rare, it is a serious complication of internal fixation in hip fractures. It occurs in 0.2%-0.3% of hip surgeries1 and can be caused by tools used for reduction or drilling during proximal femoral nailing, leading to intractable complications such as false aneurysm, hematoma, and anemia.2-5 However, such an injury is often missed or found late,6,7 and systemic complications frequently occur in older patients with anemia.8 Therefore, the prevention of DFA injury plays an important role in the surgical outcomes of hip fractures.

Accurately locating the DFA is essential to avoid injury. Several studies have investigated the high-risk vertical range and axial angle of DFA injuries using computed tomography angiography (CTA). Mahmoud et al.9 found that the risk range was 50-80 mm distal to the lesser trochanter (LT), and the risk angle was 6.6° to -12.8° from the lateral femoral cortex based on the femoral trans-epicondylar axis (TEA). Jaipurwala et al.10 reported that the risk ranges, as measured from the tip of the greater trochanter (DS), were 110-120 mm and 120-130 mm in women and men, respectively. Although DFA injury could be minimized by avoiding the drilling of only the vertical range based on these results, it is difficult to confirm the axial angle based on the TEA intraoperatively because the TEA can only be measured using computed tomography (CT). Thus, a novel high-risk vertical range and axial angle of DFA injury that can be easily confirmed during surgery are needed. Accordingly, we focused on the femoral neck axis and femoral shaft axis as the confirmable indicators using fluoroscopy intraoperatively. Based on the axial risk angle, fluoroscopy may help confirm whether the femoral neck and femoral shaft are on the same straight line in the lateral view and may check the angles during surgery. Indicators for the course of DFA that are easy to confirm intraoperatively using fluoroscopy allow surgeons to minimize the intraoperative risk of...
DFA injury. To the best of our knowledge, there are no reports estimating the high-risk ranges of DFA injury in lateral view fluoroscopy matched with CT estimation.

Herein, we aimed to determine the novel indicators of the high-risk axial angle and distances from the bone cortex for DFA injury that can easily be confirmed intraoperatively during proximal femoral nailing.

Materials and Methods

Study design and population

This retrospective study screened 119 Asian patients (68 men and 51 women) who underwent CTA in our hospital between April 2018 and July 2020 to estimate the blood circulation in the lower limbs. Seventeen patients were excluded because of a history of hip fractures (n = 7), hip osteoarthritis (n = 2), vascular occlusion (n = 2), and unmeasurable data (n = 6). Further, 14 patients aged <60 years were excluded because the number of patients with hip fractures is high in the age group of >60 years in the Japanese population. Finally, the study population comprised 88 Asian patients.

Patients were placed in the supine position, and their lower limbs were secured on the table used for CTA (Aquilion, Toshiba, Tokyo, Japan). The axial slice thickness is 2 mm and the slice gap is <2 mm. Gong et al. reported that DFA injury is usually caused by the excessive lengths of the distal screws or overpenetration of a drill bit. Thus, 2 slices of the CTA axis were chosen as the reference points. The first point was the lower end of the LT because the reduction tools are often inserted into this point during proximal femoral nailing. The second point was the distal femur, 140 mm from the tip of the DS. In our hospital, the Gamma3 system (Stryker, Kiel, Germany) is used in surgery, and a distal screw is inserted into a static hole. This nail is then drilled for the distal screw fixation at approximately 140 mm distal from the tip of the nail.

Definitions and calculations

View R (Sade Qwest, Osaka, Japan) was used for image analysis. To easily check the plane intraoperatively using fluoroscopy, the reference plane was defined as the femoral neck and femoral shaft on the same straight line in the lateral view and the plane passing through the center of the femoral neck and shaft (Figure 1). High-risk range was estimated by matching the plane of intraoperative lateral view in fluoroscopy and CT which was mapped in intraoperative lateral view. To determine the high-risk angle of DFA injury based on the reference plane, the bone–arterial angle (BAA), from the reference plane to the DFA, was measured at the LT and DS. The BAA was calculated from the cross-sectional image of the CTA, assuming a lateral view intraoperatively using fluoroscopy. First, to reproduce the same reference plane on the CT as the lateral view on the fluoroscopy (Figure 1), the femoral neck axis was defined as the line through the center of the 2 circles in contact with the cortical bone of the femoral neck at the most proximal level where the medial calcar cortex appeared. The femoral neck angle (α) was measured as the angle formed by the femoral neck axis and the parallel line of the CT table (Figure 2). Second, the line connecting the center of the circle that contacted the cortical bone of the femur and the center of the DFA at the LT was drawn. The angle between the line and the parallel line of the CT table was measured (β) (Figure 3). Finally, the BAA at the LT (γ) was measured by subtracting α from β (Figure 4). This method allowed us to measure the angle of the DFA based on the femoral neck axis. Using the same method, the angle between the line from the center of the femur to the DFA and the parallel line of the CT table at the DS was defined as δ (Figure 5). The BAA at the DS (ε) was measured by adding –α and δ (Figure 6). These angles were notated as negative if the line was behind the parallel line of the CT table.

HIGHLIGHTS

• In this study, high-risk angles and distances of deep femoral artery (DFA) injury are estimated in the lateral view, which is easy to confirm intraoperatively using fluoroscopy.
• The high-risk ranges are measured in the same plane as the lateral view in computed tomography (CT) using the neck axis as a reference to match the planes of lateral and CT view.
• To minimize the risk of DFA injury, surgeons need to avoid using the high-risk ranges or be careful not to drill too deep in the high-risk ranges in the lateral view.
Additionally, bone–artery distance (BAD) defined as the shortest distance between the surfaces of the femur and the deep femoral artery (DFA) at the lesser trochanter (LT) was measured (Figure 7). Femoral neck anteversion is the angle between the neck axis and posterior distal femoral condyle axis. However, in our study, the neck axis was the reference to measure the range of DFA, and the line parallel to the CT table was defined as the reference line to measure \( \alpha \), \( \beta \), and \( \delta \).

We analyzed the measurements of the BAA and BAD, and the average values and standard deviations were calculated for all patients. Their correlations with body height or weight were evaluated. Additionally, we investigated whether these values differed among the sexes.

Continuous variables were presented as medians (interquartile ranges). The data were compared among the sexes using the Student’s \( t \)-test if there were equal variances or using the Mann–Whitney \( U \)-test if there were unequal variances. The correlations were analyzed using Spearman’s rank correlation coefficient technique. Statistical significance was set at \( P < .05 \). Data analyses were performed using STAT flex (Artec KK, Osaka, Japan). According to the statistical power
analysis, the power was 0.887 (post hoc power analysis: effect size: 0.73; α error prob: 0.05, sample size: 41/47, G*Power 3.1, Düsseldorf, Germany). To assess interobserver error with our measurement method, 30 patients were randomly selected and calculated by 2 of the authors, and the intraclass correlation coefficient (ICC) values were calculated using SPSS for Mac version 26 (IBM Corp., Armonk, NY, USA). Because of the anonymous nature of the data, the requirement for informed consent was waived, and this was notified on our home page. This study protocol was approved by our hospital’s institutional review board (K381-20200805).

Results

Fifty men and 38 women [mean age (range), 75.5 ± 8.4 (61-95) years; mean body weight (range), 55.2 ± 11.7 (30.3-86.0) kg] were included. There was no significant difference between the ages among men and women [74.7 ± 8.1 (61-95) years and 76.5 ± 8.6 (61-94) years, respectively; \( P = .328 \)]. Body height and weight were significantly different among men and women (165.0 ± 6.8 [148.0-183.1] cm versus 152.9 ± 6.7 [135.0-165.9] cm, \( P < .0001 \); and 50.7 ± 10.4 [33.4-86.0] kg vs. 49.2 ± 10.8 [30.3-73.4] kg, respectively, \( P < .0001 \)).

At the LT, the mean BAA and BAD were 19.2° ± 8.0° (4.0-41.7) and 22.9 ± 4.7 (10.4-33.3) mm, respectively. Overall, at the DS, the mean BAA and BAD were −33.9° ± 17.0° (−72.8 to 26.4) and 11.3 ± 4.1 (2.0-23.3) mm, respectively (Figure 8). The ICC values were 0.988 (95% CI 0.976-0.994; LT BAD), 0.997 (95% CI 0.995-0.999; LT BAA), 0.995 (95% CI 0.990-0.998; DS BAD), and 0.998 (95% CI 0.996-0.999; DS BAA) for interobserver agreement. The mean BAD at the LT was significantly longer in men than in women. The mean BAA at the LT, BAA at the DS, and BAD at the DS were not significantly different among the sexes (Table 1).

At the LT, positive correlations were observed between body height and both BAA and BAD. Body weight and BAD at the LT were positively correlated. In contrast, there was no correlation between body weight and BAA at the LT. At the DS, there were negative correlations between body height and BAA and between body weight and
There were no correlations between body height and BAD and between body weight and BAD (Tables 2, 3).

**Table 1.** The difference about LT and DS between sexes

|                | Total (n = 88) | Men (n = 50) | Women (n = 38) | P  |
|----------------|---------------|--------------|----------------|----|
| BAA (°)        |               |              |                |    |
| LT             | 19.2 ± 8.0    | 20.0 ± 8.6   | 18.4 ± 6.8     | 0.3571 |
| DS             | –33.9 ± 17.0  | –32.3 ± 17.1 | –36.0 ± 16.6   | 0.3243 |
|                | (–72.8 to 26.4)| (–61.1 to 5.5)| (–72.8 to 26.4)|     |
| BAD (mm)       |               |              |                |    |
| LT             | 22.9 ± 4.7    | 24.1 ± 4.5   | 21.4 ± 4.5     | 0.0062 |
| DS             | 11.3 ± 4.1    | 11.4 ± 4.1   | 11.2 ± 4.0     | 0.8010 |
|                | (2.0-23.3)    | (2.0-23.3)   | (2.0-23.3)     |     |

**Table 2.** Correlations between LT and DS and body weight

|                | r      | P    |
|----------------|--------|------|
| BAA (°)        |        |      |
| LT             | 0.0826 | 0.444|
| DS             | –0.3377| 0.0013|
| BAD (mm)       |        |      |
| LT             | 0.3667 | 0.0004|
| DS             | 0.0788 | 0.4657|

**Table 3.** Correlations between LT and DS and body height

|                | r      | P    |
|----------------|--------|------|
| BAA (°)        |        |      |
| LT             | 0.3729 | 0.0003|
| DS             | –0.5671| <0.0001|
| BAD (mm)       |        |      |
| LT             | 0.4556 | <0.0001|
| DS             | –0.0694| 0.5203|

**Discussion**

We showed novel high-risk angles and distances for DFA injury that can be easily confirmed during surgery using fluoroscopy for hip fractures in Asian people. These results will help surgeons minimize the intraoperative risk of DFA injury during invasive reduction around the LT and drilling for distal screw fixation in hip fractures because the reference plane can be recognized easily by fluoroscopy intraoperatively. To the best of our knowledge, this is the first report to indicate the risk angles and distances from the femoral bone surface for DFA injury based on the plane according to patients’ intraoperative posture. The benefit of this method is that only fluoroscopy is used, which is already necessary for proximal femoral nailing with a traction table. After the reduction, the nail is inserted in the plane in which the femoral shaft and the neck are aligned using fluoroscopy. In this plane, the high-risk range is more than 17° toward the posterior side for the drill of the distal screw. When surgeons insert proximal guide wire, they need to confirm the direction of the distal screw by drill guide and avoid the high-risk range. If the direction of the drill for the distal screw is in the high-risk range, pressing the fracture point from the anterior side would help surgeons to avoid this range. Pressing the fracture point manually from the anterior side may increase the anteversion of the femoral neck, and the angle of the lag screw increases anteriorly to the femoral shaft axis. As a result, the nail is externally rotated, and the direction of distal drilling also changes toward the anterior side (Figure 9). Nevertheless, if the surgeon is unable to avoid the risk range while drilling the distal screw, it would be important to be careful not to drill too deep.

The clinical benefit of our high-risk ranges and distances for DFA injury is that the location of the DFA during surgery can be predicted easily. Previous studies have investigated these factors. Mahmoud et al9 reported that based on the TEA, the range was 22° on the anterior side and the distance was 31.4 mm from the surface of the femur at the LT, while the range was 22° on the posterior side and the distance was 9.6 mm from the surface of the femur at 100 mm from the LT. However, this indication is not considered to be applicable for preventing DFA injury intraoperatively because it is not easy to confirm the TEA intraoperatively. Jaipurwala et al10 reported that the risks were high at 110-120 mm from the tip of the DS in women and 120-130 mm in men. However, this report investigated only the vertical range. Thus, it is clinically difficult to avoid DFA injury by altering the drilling angle because the risk angle is difficult to identify. However, our findings make it easy to confirm the risk angles and distances by adjusting the rotation of the femur in the lateral view with fluoroscopy during surgery, thereby enabling surgeons to prevent DFA injury.

Herein, the DFA was closer to the surface of the femur in women than in men at the LT. Jaipurwala et al10 reported that the perforator of the DFA was 10 mm proximal in women compared with that in men. Thus, knowing the sex difference in the DFA location is especially important for preventing DFA injury. Moreover, the BAA was
positively correlated with body weight, and the BAD had a positive correlation with body height and body weight at the LT. However, the BAA was negatively correlated with body height and weight at the DS. This means that the location of the DFA is affected by one’s physical constitution, and it is an important factor in predicting the high-risk ranges in accordance with the difference in one’s physical constitution.

Several previous reports have confirmed the location of the vascular lature around the hip. Han et al.13 reported that the risk ranges of arterial injury were different depending on the types of nails when implementing CT. Since our hospital used Gamma3 for proximal femoral nailing for trochanteric fractures, with the distal static hole 140 mm from the tip of the nail—a distance specifically determined for this study. Davis et al.14 reported that the mean femoral artery and vein course was 21 mm anterior to the anterior capsule in cadavers. In patients with a leg holder and perineal post, the distances between the superficial femoral artery and femur at the point of the perineal post were 14.0 and 6.2 mm in the neutral position and during adduction, respectively.15 Among those studies, the only reproducible method during surgery for predicting the vascular location might be ultrasonography. Although ultrasonography is considered useful for detecting vascular location intraoperatively, it requires a proficient technique and time. Furthermore, it may be difficult to confirm the position of the DFA by ultrasonography at the DS level because it is located on the posterior side of the femur. Our reference plane allows easy prediction of the DFA location by only adjusting the rotation of the femur so that the femoral neck and shaft axis are on the same line in the lateral view intraoperatively.

Our study has some limitations. First, only the trunk of the DFA without branches was examined. Because trunk injury causes more serious complications than branch injury, we prioritized the trunk of the DFA. Investigation of the branches is a subject for future study. Second, the preoperative anatomical changes in soft tissue swelling and displacement of the femur caused by fracture and images taken on the traction table during surgery were not considered. It is difficult to estimate the anatomical changes due to these because the degree of dislocation varies among patients and obtaining CT under-ly tra tion of a Neck of Femur Fracture with a Compression Hip Screw. Case Rep Orthop. 2013;2013:181293. [CrossRef]

Yang X, Wu Q, Wang X. Investigation of perioperative hidden blood loss of unstable intertrochanteric fracture in the elderly treated with different intramedullary fixations. Injury. 2017;48(6):1848–1852. [CrossRef]

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With the knowledge that the location of the DFA is influenced by sex differences and physical constitution, the high-risk angles and distances can be easily confirmed during proximal femoral nailing fracture, which will help minimize the intraoperative risk of DFA injury.

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