Estimating the optimal entry point of the antegrade femoral nailing: Previous and novel morphometric measurements

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Abstract

Objective: This anatomical study aimed to investigate the possible relationships between the proximal femur parameters and verify the optimal entry point in line with the medullary canal.

Methods: Both in single image series and 3D-MPR views, 63 femur bones were evaluated. One-millimeter multidetector computed tomography scans were collected and assessed by OsiriX-Lite version 8 and Horos v3.3.5. Entry point locations, projected and true femoral neck-shaft, anteversion, and newly defined nail entrance angles were measured.

Results: The entry points of 16 femurs were placed at the tip of the greater trochanter, and the remaining 47 femurs were in the trochanteric fossa (i.e., piriformis fossa). Thirty-three of the entry points found in the trochanteric fossa were overlapped by the greater trochanter. When the parameters of the right and left sides were compared, it was found that: projected neck angle, nail entrance angle, and the differences between true neck angle and nail entrance angle were found significantly different. The relationship between nail entrance angle and entry point localization was assessed, and the probability of the entry point being at the tip of the greater trochanter is 63 times greater when the NEA is below 90.

Conclusion: This study has demonstrated that the ideal entry point for straight nails, which is based on the anatomic axis of the femur, is found mainly at the trochanteric fossa, and the greater trochanter overlapped 70.21% of them.

Level of Evidence: Level IV, Diagnostic Study

Introduction

The morphology of the proximal femur varies among individuals and has been a matter of debate in orthopedic surgery.1,4 Since the intramedullary nail fixation is considered as “gold standard” treatment for unstable intertrochanteric fractures and midshaft fractures of femur and also often used in proximal femoral fractures, a detailed knowledge of anatomy of proximal femur is essential for a successful nailing.3,10 The correct entry point (EP) in a straight antegrade femoral nailing has been controversial in the literature and significant complications which are related to the incorrect EP have been reported.4,5,13,21 Therefore, the main goal for defining the optimal EP in line with the medullary canal should implicate a tenseless introduction of the nail.5,11 In view of the literature, 4 main landmarks have been recommended for straight antegrade femoral nailing: the tip of the greater trochanter (GT), the piriformis fossa (medial border of the GT), the junction of the femoral neck and trochanter, and digital or trochanteric fossa; nevertheless, the commonly used EPs are the piriformis fossa and tip of the GT.4,11,17,22,23 The trochanteric fossa is a depression, found on the outer surface of GT, that is also known as the digital fossa and most of the previous studies in the literature have entitled it incorrectly as piriformis fossa.21,24,25 The piriformis fossa is a small depression of the insertion point of the piriformis muscle and it is found on the tip of the GT.20 The trochanteric fossa is more in line with the medullary canal and it is the recommended EP for straight antegrade femoral nailing.3,11,14 In some cases, trochanteric fossa may be masked with a trochanteric overhang and therefore EP has to be shifted medially.3,4,16 In addition, using a more medial EP than GT may sometimes increase the complications such as avascular femoral head necrosis or additional fractures.3,4,16 Obviously, EP may vary among patients due to the anatomical discrepancies, such as the varus-valgus angulation of the neck, and also it should be determined according to the implant that is chosen.20,31,16 Therefore, knowing the morphometric characteristics of the femur is important in terms of surgical success and decreasing the risk of complications. The main purpose of this anatomical study was to investigate the possible relationships between the parameters of the proximal femur and to verify the optimal EP according to the straight nail, in line with the medullary canal.
Materials and Methods

Eighty-eight human femur bones of unknown gender were evaluated. This study began after the approval from the ethical board (GO 19/54-2019/03-19). The bones with fractures, erosions, and deformities on the proximal part were excluded from the study and the 63 bones (36 right and 27 left) were included. The imaging procedures were done by Toshiba Alexion (Toshiba Medical Systems, Tokyo, Japan) 16 slice multidetector computed tomography (MDCT) with 80 kV and 37 mA protocol. One-millimeter scans for the entire length of femurs were collected. All images were evaluated by using OsiriX-Lite version 8 (Pixmeo, SARL, Switzerland) and Horos v3.3.5.

All markings were performed on both anteroposterior single-image series of computed tomography (CT) scans identical to the x-ray image, and images which were obtained by using the OsiriX-Lite’s 3-dimensional multi-plane reconstruction (3D MPR) function in axial, sagittal, and coronal planes. Using the 3D MPR function, all points were determined in all 3 planes simultaneously. In this manner, 3D evaluations of markings and measurements were provided. Parameters were defined according to straight nail type and the report of Anastopoulous et al.11

Markings

Using both anteroposterior single-image series and 3D MPR images, centers of the femoral head (Ch) and neck (Cn), and 3 respective points in the centers of the medullary canal of the proximal half of the femur were determined. Two lines which were passing through these respective points within the medullary canal were stated: 1 line in the anteroposterior single-image series (M1) and another line (M2) at the 3D MPR coronal plane images. In this way, the central axis of the neck was found or not. In the single-image series, the angle between neck axis and line M1 was measured as the projected femoral neck-shaft angle (pNA) (Figure 2a) and also at the 3D MPR views angle between the respective points in the medullary canal; EP, entry point; GTL, the most lateral point of greater trochanters; F, fovea, tip of greater trochanter; CT, computed tomography; 3D MPR, 3-dimensional multi-plane reconstruction.

Measurements

First, the EPs locations were identified at the 3D MPR views. Later on, EPs which had been found at the trochanteric fossa were analyzed at rendered 3D surface images to assess whether trochanteric overhang was found or not. In the single-image series, the angle between neck axis and line M1 was measured as the projected femoral neck-shaft angle (pNA) (Figure 2a) and also at the 3D MPR views angle between the neck axis and line M2 was evaluated as the true 3D femoral neck angle (tNA) (Figure 2b). In addition, the angle between the line from Cn to EP and line M2 was defined as the nail entrance angle (NEA) (Figure 2c). The distances between EP-F, EP-GTL, and GTL-F were considered to be statistically significant.

Results

Of the examined 63 femoral bones, 36 were right-sided and 27 were left-sided. The EPs of 16 femurs were placed at the tip of the GT and the remainder 47 femurs’ EPs were found at the trochanteric fossa (Figure 4). Among the EPs that were found in the trochanteric fossa, 33 of them were overlapped by GT and described as (+) and 14 were not and described as (−) (Figure 5). The mean values of all parameters with respect to the EP location are shown in Table 1. When the parameters of right and left sides were compared, it was found that pNA, NEA, and the differences between tNA and NEA were significantly different (P < .05) (Figure 6). According to the 2-tailed Spearman’s correlation test, the tNA had a moderate positive correlation with pNA (r = .453, P < .001) and NEA (r = .454, P < .001). There was also a moderate positive correlation between NEA and pNA (r = .655, P < .001) (Table 2). Comparison of parameters between the EP locations was assessed by using the Mann–Whitney U test. There were significant differences for EP-F, F-GTL, pNA, NEA, and the difference between TNA – NEA and pNA – NEA (P < .05) (Figure 7). To assess the relationship between NEA and EP localizations, cross-tabulation was used. When the NEA is below 90°, the...
probability of the EP being at the tip of the GT is 63 times greater [OR] (95% CI: 7.4-544.1) with 93.8% sensitivity and 80.9% specificity (Table 3). The calculated positive predictive value and negative predictive value for EP were 62.5% and 80.9%, respectively. Receiver operating characteristic curve analysis was used to obtain the cut-off value for NEA using the areas under the curve (AUC) (AUC: 0.935; 95% CI: 0.873-0.997).

Discussion
Antegrade femoral nailing has become the standard procedure for femoral shaft and unstable intertrochanteric fractures and, in this sense, knowing the anatomy of the related features became more of an issue. Choosing the correct EP to avoid complications is one of the main objectives of the procedures. In the present study, the proximal femur anatomy and possible relationships between the structures were evaluated radiographically on dry femurs by using MDCT. Besides well-known morphometric measurements, a newly defined angle known as “the NEA” was highly related to the EP and was found statistically significant.

Entry point and trochanteric overhang
According to the results of this study, 47 (74.6%) of the evaluated 63 femurs’ central axis of the medullary canal was located at the trochanteric fossa, which was assumed as the optimum anatomical EP of a straight antegrade intramedullary nailing. On the other hand, in 25.39% of the femur, the ideal EP was found to be at the tip of the GT. The second finding is that the EP in 33 samples (70.21%) were overlapped by GT and 14 (29.78%) were not. In daily practice, the trochanteric overhang may complicate the approach through the trochanteric fossa as it covers the area. This should be diagnosed preoperatively to prevent the possible complications such as being more proximal than anticipated which can cause avascular necrosis or a fracture of the femoral neck. In such a case, instead of using a straight nail, a proximal bent nail entering through the tip of the GT can be selected. Many other studies have been carried out similarly about the EP locations and trochanteric overhang. For instance, Byun et al3

Figure 2. a-c. (a) Projected femoral neck-shaft angle (pNA) was demonstrated at single-image series. (b) True 3D femoral neck angle (nNA) was calculated with the 3D MPR function at the coronal plane. (c) Nail entrance angle (NEA) was calculated with the 3D MPR function at the coronal plane. Cc, center of the head; Cn, center of the neck; EP, entry point; 3D MPR, 3-dimensional multi-plane reconstruction.

Figure 3. The femoral anteverision angle (AV) was measured according to certain points at the 3D rendered images. Ch, center of the head; Cn, center of the neck; 3D, 3-dimensional.

Figure 4. a, b. 3D MPR coronal plane images. (a) The entry point at the tip of the greater trochanter. (b) The entry point in the trochanteric fossa. EP, entry point; M2, line passing through these respective points in the medullary canal; 3D MPR, 3-dimensional multi-plane reconstruction.
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rendered the CT images of 103 cadavers into 3D images and reconstructed the medullary canal. They reported that 68 (66.0%) of the models’ EPs were in trochanteric fossa and trochanteric overhang was seen in 50 (48.3%). In another study, 500 patient with femoral shaft fracture were treated by intramedullary nailing through the piriformis fossa. Consequently, in that study, Winquist et al strongly recommended the piriformis fossa, which is found just medial to the GT, as the starting point. In fact, the correct name of the EP they suggest is the trochanteric fossa and it is compatible with the literature. Ricci et al treated 91 patients with femoral shaft or sub-trochanteric fracture, either nailing through greater trochanter (38%) or through piriformis fossa (58%). According to their results, healing and

Table 1. The mean values of all parameters with respect to the entry point location

| Parameters | Trochanteric Fossa | Tip of the Greater Trochanter |
|------------|------------------|------------------------------|
| tNA (°)    | 124.27 120.46 128.90 124.52 6.46 122.75 118.14 127.76 122.91 6.05 | 118.14 127.76 122.91 6.05 |
| pNA (°)    | 130.54 127.20 136.06 131.17 6.55 123.81 120.62 127.99 124.86 5.36 | 120.62 127.99 124.86 5.36 |
| NEA (°)    | 96.66 91.03 106.82 95.83 8.93 83.23 77.41 85.77 81.56 6.03 | 83.23 77.41 85.77 6.03 |
| AV (°)     | 15.72 7.59 19.66 15.47 9.85 16.66 11.18 24.12 17.91 8.93 | 11.18 24.12 17.91 8.93 |
| tNA-NEA    | 27.73 23.78 32.84 28.70 6.55 41.53 37.60 45.69 41.35 6.49 | 41.53 37.60 45.69 6.49 |
| pNA-NEA    | 36.45 29.76 39.42 35.44 7.33 44.00 38.69 46.66 43.30 4.90 | 44.00 38.69 46.66 4.90 |

SD, standard deviation; tNA, 3D femoral neck angle; NEA, nail entrance angle; AV, anteversion angle; pNA, projected femoral neck-shaft angle.

Figure 5. a, b. Rendered 3D surface images. (a) Entry point overlapped by greater trochanter. (b) Entry point not overlapped by greater trochanter. GT, greater trochanter. Red point indicated by a yellow arrow denotes the entry point.

Figure 6. a-c. Mean values of the parameters that were statistically significant when compared between right and left sides. (a) Projected neck angle (pNA). (b) Nail entrance angle (NEA). (c) Difference between true neck angle (tNA) and nail entrance angle (NEA).
Table 2. Correlation of the parameters (2-Tailed Spearman’s Correlation Test)

| Parameter            | EP − GTL (cm) | EP − F (cm) | F − GTL (cm) | tNA (◦) | pNA (◦) | NEA (◦) | AV (◦) |
|----------------------|---------------|-------------|--------------|---------|---------|---------|--------|
| EP−GTL (cm)          | r             | 1.000       | 0.438**      | 0.649†  | 0.027   | −0.228  | −0.296† | −0.206 |
|                     | P             | 0.000       | 0.000        | 0.831†  | 0.072   | 0.018   | 0.105  |
| EP−F (cm)            | r             | 0.438**     | 1.000        | 0.814†  | −0.274† | −0.519† | −0.541† | −0.150 |
|                     | P             | 0.000       | 0.000        | 0.030   | 0.000   | 0.000   | 0.240  |
| F−GTL (cm)           | r             | 0.649†      | 0.814†       | 1.000   | −0.104  | −0.238  | −0.326† | −0.222 |
|                     | P             | 0.000       | 0.000        | 0.418   | 0.060   | 0.009   | 0.080  |
| tNA (◦)              | r             | −0.027      | −0.274†      | −0.104  | 1.000   | 0.453†  | 0.454†  | 0.208  |
|                     | P             | 0.831†      | 0.030        | 0.418   | 0.000   | 0.000   | 0.102  |
| pNA (◦)              | r             | −0.228      | −0.519†      | −0.238  | 0.453†  | 1.000   | 0.655†  | 0.128  |
|                     | P             | 0.072†      | 0.000        | 0.000   | 0.000   | 0.000   | 0.317  |
| NEA (◦)              | r             | −0.298†     | −0.541†      | −0.326† | 0.454†  | 0.655†  | 1.000   | 0.092  |
|                     | P             | 0.018†      | 0.000        | 0.009   | 0.000   | 0.000   | 0.475  |
| AV (◦)               | r             | −0.206      | −0.150       | −0.222  | 0.208   | 0.128   | 0.092  | 1.000  |
|                     | P             | 0.105†      | 0.249        | 0.000   | 0.102   | 0.317   | 0.475  |

EP, entry point; GTL, the most lateral point of the greater trochanter; F, fovea; NEA, nail entrance angle; pNA, projected femoral neck-shaft angle.

The significance of bold values was explained in the results section. According to the 2-tailed Spearman’s correlation test, the tNA had a moderate positive correlation with pNA (r = 0.453, P < 0.001) and NEA (r = 0.454, P < 0.001). There was also a moderate positive correlation between NEA and pNA (r = 0.655, P < 0.001) (Table 2).

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Cross-tabulation of NEA value and EP location

| NEA (◦) (Binned) | Count | GT Location | TF Location | Total |
|------------------|-------|-------------|-------------|-------|
| ≤90.00           |       | 15          | 9           | 24    |
| % within NEA (◦) (binned) | 62.5% | 37.5% | 100.0% |
| % within EP location | 93.8% | 19.1% | 38.1% |
| 90.01+            |       | 1           | 38          | 39    |
| % within NEA (◦) (binned) | 2.6%  | 97.4% | 100.0% |
| % within EP location | 6.3%  | 80.9% | 61.9% |
| Total             |       | 16          | 47          | 63    |
| % within NEA (◦) (binned) | 25.4% | 74.6% | 100.0% |
| % within EP location | 100.0% | 100.0% | 100.0% |

NEA, nail entrance angle; EP, entry point; GT, greater trochanter; TF, trochanteric fossa.

When the NEA is below 90°, the probability of the EP being at the tip of the GT is 63 times greater [OR (95% CI: 7.4-544.1) with 93.8% sensitivity and 80.3% specificity.

Figure 7. a-f. Box-plots illustrating the comparison of significant parameters between the entry point locations. TF, trochanteric fossa; GT, tip of the greater trochanter. (a) Distance between entry point (EP) and fovea (F). (b) Distance between fovea (F) and the most lateral point of the greater trochanter (GTL). (c) Projected neck angle (pNA). (d) Nail entrance angle (NEA). (e) Difference between true neck angle (tNA) and nail entrance angle. (f) Difference between projected neck angle (pNA) and nail entrance angle (NEA).
complication rates were found to be similar between both points.\textsuperscript{17} Consequently, they considered that using the GT as an EP by specifically designed nails and specific techniques can be an alternative method to the piriformis fossa.\textsuperscript{15} According to the EP that has been chosen, the nail type may vary. Therefore, it is necessary to evaluate the anatomy of the patient before the procedure to decide on the appropriate nail. According to the literature, bend nails are more suitable for mediolaterally located EPs.\textsuperscript{4,16} Thereafter, determining the proximal projection of the medullary canal preoperatively can reveal the correct EP. Grechenig et al\textsuperscript{16} classified the relationship between the anatomy of GT and EP into 4 groups. They investigated 100 cadaver femurs' piriformis fossa (trochanteric fossa) and 12 of them were partially and 25 of them were fully overlapped by GT. Also, Wang et al\textsuperscript{27} categorized the overhang situations of GT into 5 types. Preoperative and postoperative anteroposterior (AP) x-ray images of 213 hips were evaluated and they found that the trochanteric overhang in 175 of them exceeded the axis of the medullary canal.\textsuperscript{27} These results indicate that surgeons should be cautious that the EP is not always found in line with the medullary canal. Therefore, thorough preoperative planning (i.e., AP x-ray of the contralateral femur) is mandatory in order to decrease possible complications. Variations of the GT can also make it difficult to identify the ideal EP.\textsuperscript{3,14} For this reason, the morphological structures of the GT and the type of nail to be used should be evaluated with the radiological evaluations before surgery.

Nail entrance angle

In the current study, besides well-known measurements, the angle between the line from $C_t$ to EP and line of medullary canal ($M_t$) was defined as the NEA. The statistical analysis showed a strong correlation between NEA and the location of the EP. When NEA is below 90° the probability of the EP being at the tip of the GT is 63 times greater. As the angle decreases, it leads to lateral positioning of the EP. The clinical relevance of this result is that the NEA can easily be evaluated preoperatively at AP and lateral radiography and may guide the surgeon in choosing the correct nail entrance point and proper nail type. Although the EP was not standard, its relation to the anatomy of GT and EP into 4 groups. They investigated 100 cadaver femurs' piriformis fossa (trochanteric fossa) and 12 of them were overlapped by GT. Further studies with high quantity of specimens and for different nailing systems should be carried out. The NEA is highly related to EP and further radiological and in vivo studies for different nailing systems could enhance this parameter and support the clinical significance. This study determined optimum results according to straight nails and aimed to reveal the ideal anatomical points. Results may vary according to the nail type. Correlations between different nail types can be studied in further studies. However, despite these limitations, the data of the study could be valuable for surgical procedures.

Defining the ideal localization of the EP of antegrade femoral nailing preoperatively is essential for maintaining the functional reduction and preventing complications. In this study, it was demonstrated that the ideal EP for straight nails which is based on the anatomic axis of the femur is found mostly at the trochanteric fossa and 70.21% of them were overlapped by GT. Further studies with high quantity of specimens and for different nailing systems should be carried out. The NEA is highly related to EP and further radiological and in vivo studies for different nailing systems could enhance this parameter and support the clinical significance. This study determined optimum results according to the anatomical axis of femur and the relations of the EPs with the proximal femoral structures. In order to ensure a correct position for intramedullary nailing, all these variations should be kept in mind.

Other morphometric evaluations

During evaluations, other morphometric measurements were also evaluated. The distances between GTL-F and EP-F were significantly related to the EP locations as expected. As the EP located at the tip of the GT, the distance between EP-GLT and F-GLT increases. In this study, projected neck angle (pNA), NEA, and the differences between tNA and NEA were found to be significantly different between right and left sides, but the limitation of this finding is that the femurs did not belong to the same individual. These findings may be related to the dominancy of the sides and should be evaluated in in vivo studies. Additionally, it should be kept in mind that there may be differences between the right and left sides and should be evaluated with the contralateral side before surgery.

The main limitation of this study is that it was carried out on dry femurs. The number of the examined specimens is small and also the age, gender, and physical conditions were unknown. Moreover, evaluations have been made according to straight nails and aimed to reveal the ideal anatomical points. Results may vary according to the nail type. Correlations between different nail types can be studied in further studies. However, despite these limitations, the data of the study could be valuable for surgical procedures.

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