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Original Research

How to Estimate Femoral Stem Anteversion During Direct Anterior Approach Total Hip Arthroplasty

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ABSTRACT

Background: There are various traditional landmarks used to estimate the femoral component version, yet none are widely accepted by direct anterior surgeons. The purpose of this study was to compare bony landmarks easily accessible to direct anterior surgeons and to estimate which one provides the best estimate of femoral component anteversion.
Methods: A computed tomography database was used to identify 736 left entire-femur computed tomography scans. Seven visible anatomic landmarks were identified using a computer model in which a 45° virtual neck resection was made at 10 mm above the lesser trochanter. Thirteen axes, to reference the femoral stem position, were created between the 7 landmarks. Means and standard deviations (SDs) of angles between each axis and the transepicondylar axis (TEA) were compared for their precision.
Results: The traditional lesser trochanter predicted anteversion from the TEA was 34.1° (SD 9.7°). Predicted anteversion from the TEA was 3.3° (SD 8.1°) when aligned from the center of the canal to the middle of the medial calcar; 14.0° (SD 8.1°) from the center of the canal to the anterior 1/3 of the medial calcar; and 24.8° (SD 8.5°) from the center of the canal to the most anterior point on the medial calcar.
Conclusions: Compared to the lesser trochanter, 7 axes were more precise (lower SD) when predicting the version. Estimating the femoral component position, via simulated data, using 3 points along the medial calcar is a relatively precise and easily accessible tool for surgeons.

Introduction

Femoral anteversion is defined by the angle between the transepicondylar axis (TEA) of the distal femur and the stem-neck axis [1,2] in the axial plane. Surgeons use intraoperative landmarks to estimate the distal femur TEA for placement of the femoral component version during total hip arthroplasty (THA). Accuracy and precision in this positioning are essential in producing a stable THA [3,4] and decreasing complications such as impingement and dislocation [5,6]. Much emphasis has been placed on the acetabular position, with limited literature focusing on the femoral component anteversion and intraoperative targeting and techniques.

Several publications have demonstrated that surgeon accuracy and precision is less than perceived. One study found that 54% of femur implants were placed outside of the intended target of 10°-20° of anteversion [2]. Wines et al. studie surgeon estimates of femoral anteversion in 111 primary total hip replacements and found that 103 (93%) were estimated to be either 15° or 20⁰. Yet only 71% of implants evaluated by computed tomography (CT) scans were between 10° and 30° anteversion and surgeon estimates were found to range from 25° underestimation to 30° overestimation [4].

Previous studies have identified certain intraoperative landmarks that surgeons can use to assess femoral anteversion [7,8]. Some of these include the stem position relative to the condylar plane of the femur, the lesser trochanter, and the position of the stem relative to the lower limb position held in space [7-9]. Some have even used digital protractors and a spirit level, a tool used to indicate whether an object is parallel or perpendicular, intraoperatively to accurately obtain proper stem anteversion [10]. These studies, however, focus on techniques more relevant to the posterolateral approach [1,2,4,7,9,10].

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The primary purpose of this study was to identify easily accessible and identifiable landmarks for direct anterior (DA) surgeons and to compare the precision of these landmarks in estimating femoral anteversion. Secondarily, we compared the precision of these novel landmarks to a more traditional landmark, the lesser trochanter.

Material and methods

Biomorphometric CT database

A CT-scan-based modeling and analytics system, composed of scans of over 25,000 bone segments, was used for this study (SOMA, Stryker, Mahwah, NJ) [11]. All scans were obtained per local legal and regulatory requirements, which included ethics board approval and informed patient consent where appropriate. CT scans were acquired exclusively for medical indications such as polytrauma (20%), CT-angiography (70%), and other reasons (10%, eg, total joint replacement). All scans were performed under strict imaging requirements (no motion artifacts and a slice thickness of ≤1.5 mm) to ensure high-quality measurement capability, and the data sets were collected from hospitals and institutions from throughout the world with a focus on Europe, Asia, and North America. Out of 1735 left femora scans screened, a total of 736 left femora were included; see Table 1 for demographics. CT scans were excluded from this study after radiographic inspection if any of the following conditions were met: 1) presence of bone and joint anomalies such as severe dysplasia, extra-articular deformity from prior trauma or birth defects; 2) signs of degenerative arthritis such as presence of osteophytes or joint space narrowing; 3) evidence of previous surgery; or 4) missing segmentation of either the femoral neck, femoral head, or distal femur.

A CT computer-aided analysis software (SAAT, Stryker, Mahwah, NJ) was used to segment bone surfaces from the CT images and create constructions on a correspondence bone using predefined landmarks and user-defined points, which were then mapped onto each individual subject for analysis. This method produces reproducible and consistent constructs for each specimen, shown to have a margin of error of <2 mm and <1° and a demonstrated measurement variation of 0.2%, typically less than that of interobserver error [12,13].

CT construction and anatomical measurements

In the virtual computer environment, a standard femoral neck osteotomy for femoral preparation in THA at 10 mm proximal to the lesser trochanter and at a 45° angle to distal femoral shaft was created on all femora. Anatomic landmarks, typically visible via the DA approach at this neck-cut level, were identified: piriformis fossa, anterior cortex, posterior cortex, lateral cortex, medial calcar, anterior point of the medial calcar, the center of the canal, and the lesser trochanter (see Fig. 1a). Thirteen axes were created and projected onto the femoral neck resection plane: 1) piriformis fossa to the middle of the medial calcar; 2) piriformis fossa to anterior cortex; 3) piriformis fossa to the posterior cortex; 4) piriformis fossa to the lesser trochanter; 5) lateral cortex to the middle of the medial calcar; 6) lateral cortex to anterior cortex; 7) lateral cortex to posterior cortex; 8) lateral cortex to the lesser trochanter; 9) best fit line to 4 points on the anterior cortex; 10) best fit line to 4 points on the posterior cortex; 11) center of the canal to the middle of the medial calcar; 12) the center of the canal to the most anterior point on the medial calcar; 13) midline between the axes connecting the canal center to the medial calcar and the axis connecting the canal center to the anterior medial calcar, (See Fig. 1b). The axis from the center of the canal to the lesser trochanter was measured for comparison. In addition, the distal femur TEA was constructed as the line connecting the medial and lateral epicondylar prominences. The angle between the 13 axes described above and the distal femur TEA projected onto a plane orthogonal to the distal canal axis was calculated. Means and standard deviations (SDs) of angles between each axis and the TEA were compared for their precision. Positive values indicate the axis of interest was externally rotated, or anteverted, compared to the TEA, whereas negative values represent retroversion.

Table 1
Sample size and subject demographics included in this study.

Subjects	736
Male	395
Female	340
Age (years)	60 ± 17
Height (cm)	168 ± 11
Weight (kg)	71 ± 17
BMI (kg/m^2)	25.0 ± 5.1

BMI, body mass index.
Continuous variables are represented as mean ± SD.
Gender was unknown for one subject. Age was unknown for 9 subjects. Height, weight, and BMI were unknown for 195 subjects.

Results

The 13 axes identified had various means and SDs of predicted femoral anteversions measured from the distal femur TEA: A) piriformis fossa to the middle of the medial calcar 32.4° (SD: 8.2°); B) piriformis fossa to anterior cortex 66.8° (SD: 9.0°); C) piriformis fossa to the posterior cortex 15.5° (SD: 9.1°); D) piriformis fossa to the lesser trochanter −7.4° (SD: 10.6°); E) lateral cortex to the middle of the medial calcar −3.8° (SD: 9.3°); F) lateral cortex to anterior cortex 24.6° (SD: 13.1°); G) lateral cortex to posterior cortex −29.4° (SD: 9.0°); H) lateral cortex to the lesser trochanter −32.4° (SD: 10.3°); I) anterior cortex −10.0° (SD: 12.9°); J) posterior cortex 22.5° (SD: 11.8°); K) the center of the canal to the middle of the medial calcar 3.3° (SD: 8.1°); L) the center of the canal to the most anterior point on the medial calcar 24.8° (SD: 8.5°); M) the center of the canal to the midway point between the medial calcar and the most anterior point of the medial calcar 14.0° (SD: 8.1°) The mean and SD from the center of the canal to the lesser trochanter was on average 34.1° anteverted (SD: 9.7°). See Table 2 for results.

Precision was determined as the width of the SD varied among the outcomes. The 5 most precise axes were A) piriformis fossa to the middle of the medial calcar (SD: 8.0°), K) the center of the canal to the middle of the medial calcar (SD: 8.1°), M) the center of the canal to the midway point between the medial calcar and the most anterior point of the medial calcar (SD: 8.1°), B) piriformis fossa to the anterior cortex (SD: 8.2°), and L) the center of the canal to the most anterior point on the medial calcar (SD: 8.5°). Compared to the traditional lesser trochanter, 8 axes (K, M, A, L, B, G, C, and E) were more precise, with a lower SD, when predicting the version.

Discussion

This study is the first to use SOMA technology and full-length femur CT to identify easily visible anatomic landmarks to estimate femoral stem anteversion for DA-approach surgeons. We found that the predicted anteversion was 3.3° (SD 8.1°) when the femoral stem or broach is in line with the center of the canal to the middle of the medial calcar; 14.0° (SD 8.1°) from the center of the canal to the midway point between the middle of the medial calcar and the calcar's most anterior point; and 24.8° (SD 8.5°), from the

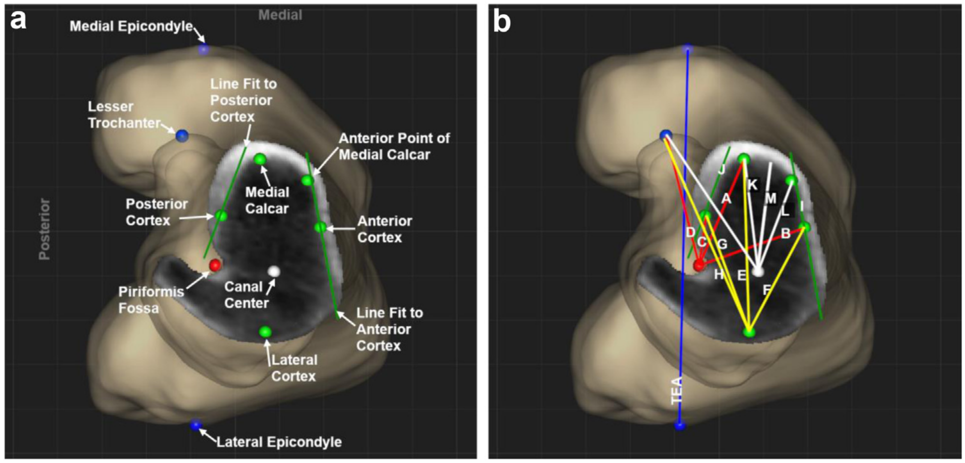

Figure 1. SOMA computer model of bony landmarks and visualized vectors. Figure depicts a representative femur CT scan sliced at the level of the neck resection with (a) the landmarks constructed and (b) the axes defined. (a-d) Axes originating from the piriformis fossa are red, (e-h) those from the lateral cortex are yellow, and (k-m) those from the canal center are white. (i-j) Axes constructed by fitting a line to multiple points are dark green. The transepicondylar axis (TEA) is shown in blue.

center of the canal to the most anterior point on the medial calcar, see Figure 2. The traditionally utilized lesser trochanter measured 34.1° (SD 9.7°) and had low precision for predicting femoral anteversion.

This simulated CT data may benefits arthroplasty surgeons, regardless of surgical approach, as landmarks are described to help predict femoral stem anteversion. If this simulated data can be applied clinically, using the medial calcar to guide femoral anteversion is easy and reliable. In our study, a stem placed directly in the middle of the calcar are predicted to be approximately 3° (SD 8.1°) from the TEA, and as the femoral component is moved along the calcar toward the anterior cortex of the femur, the anteversion will increase predictably. Stem anteversion increases to 14° (SD 8.1°) as the stem moves more anterior to the halfway point between the middle of the calcar and its confluence with the anterior cortex. As the stem approaches the point where the medial calcar meets the anterior cortex, anteversion is estimated to be 25° (SD 8.5°). Gold et al. showed that stem positioning in line with our midway to the anterior calcar position increased overall implant fit and fill and decreased stem subsidence [14].

Combined anteversion is the sum of both the femur and acetabular anteversion, which is generally agreed upon as a preventative factor against implant impingement and THA dislocation [3,5,15-17]. Widmer et al. identified 37° of combined anteversion as the target for an impingement-free range of motion using a computerized model [18]. The anteversion of the femur can have a greater effect on specific hip motions, such as sitting, bending forward, and squatting, compared to the acetabular anteversion [15]. Data from our SOMA model may give surgeons other tools to help estimate femoral anteversion when utilizing combined anteversion. Still, further clinical studies should be performed to verify femoral landmarks.

This study is not without its limitations. This was performed retrospectively on a CT-based database and was not a reflection of actual anteversion measured in postoperative patients. Anteversion was measured at a standard 10 mm above the lesser trochanter and a 45-degree angle; femoral anteversion has been shown to vary anywhere from 11.4° to 23.2° and 12.8°-21° for neck length and angle, respectively [19]. Understanding landmark precision at various neck lengths and angles should be further explored. Anteversion could also vary based on age, sex, nutritional status, ethnicity, and body mass index. Furthermore, the neck cut was taken at a point where anteversion may change at various angles of neck cuts. Also, our data set excluded cases of severe dysplasia and extraarticular deformity from prior trauma or birth defects, which may further influence femoral anteversion.

Table 2
Anteversion measurements off visual anatomic landmarks.

Vector ID	Vector description	Mean angle to TEA (deg)	Standard deviation (deg)
	Canal Center to Lesser Trochanter	−34.1	9.7
A	Piriformis Fossa to Medial Calcar	32.4	8.2
B	Piriformis Fossa to Anterior Cortex	66.8	9.0
C	Piriformis Fossa to Posterior Cortex	15.5	9.1
D	Piriformis Fossa to Lesser Trochanter	−7.4	10.6
E	Lateral Cortex to Medial Calcar	−3.8	9.3
F	Lateral Cortex to Anterior Cortex	24.6	13.1
G	Lateral Cortex to Posterior Cortex	−29.4	9.0
H	Lateral Cortex to Lesser Trochanter	−32.4	10.3
I	Anterior Cortex	−10.0	12.9
J	Posterior Cortex	22.5	11.8
K	Canal Center to Medial Calcar	3.3	8.1
L	Canal Center to Anterior Medial Calcar	24.8	8.5
M	Midway between Vector K and Vector L	14.0	8.1

Negative numbers represent retroversion, and positive numbers represent anteversion, as referenced from the transepicondylar axis (TEA) of the distal femur.

Conclusions

Our study used a database to evaluate femoral component anteversion using easy-to-access intraoperative landmarks. We found that femoral stem anteversion predictably increases from 3.3° to 24.8° as the component position moves from the center of the medial calcar to its most anterior point. Directly in between these 2 points, the stem anteversion is found to be an average of 14.0° and associated with the most precision.

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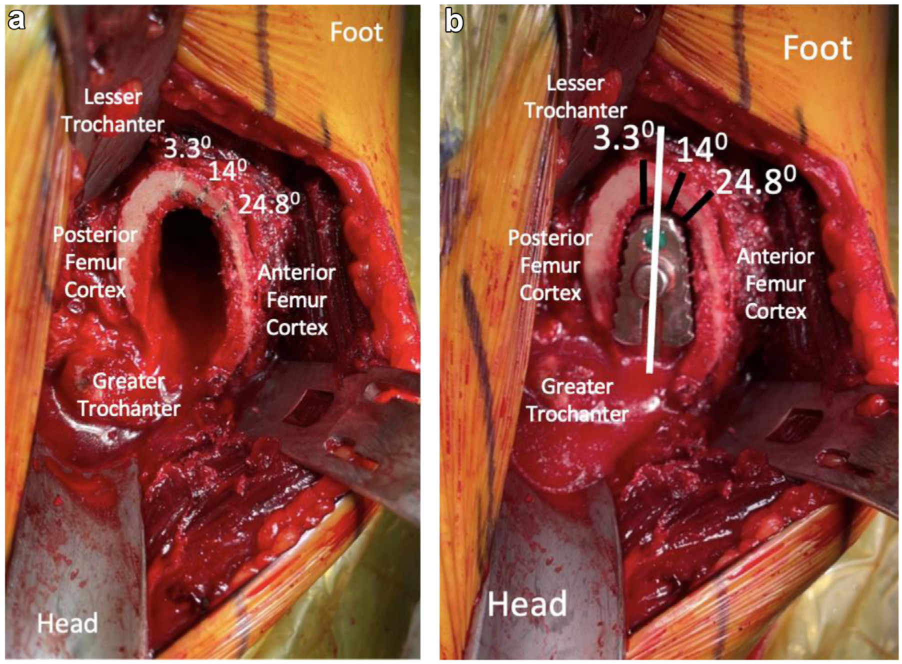

Figure 2. Intraoperative estimation of femoral stem anteversion. (a and b) shows intraoperative photos of femoral exposure during a direct anterior total hip arthroplasty. (a) Shows the 3 lines representing the estimated stem anteversion of 3.3°, 14°, and 24.8°, from left to right, respectively. (b) Shows a femoral broach in the femoral canal during sequential broaching, with the tip of the broach approximately between the 3.3° and 14° position.

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2024.101326.

CRediT authorship contribution statement

Peter A. Gold: Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Thomas F. McCarthy:** Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Ilya Borukhov:** Writing – review & editing, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition. **Jonathan Danoff:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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