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Original Research

Femoral Neck Anteversion: Which Distal Femur Landmark Matters?

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A B S T R A C T

Background: Femoral neck anteversion has traditionally been measured by the angle between the distal femur posterior condylar axis (PCA) and a line drawn through the center of the femoral head and neck. While less common, the transepicondylar axis (TEA) has also been used to reference femoral neck anteversion. The purpose of this study was to compare femoral neck version of the PCA vs the TEA using computerized tomography (CT).
Methods: A total of 1507 femoral CTs were included. Precise bony landmarks were established: lateral epicondyle, medial epicondyle, posteromedial condyle, posterolateral condyle, center of the femoral neck, and center of the femoral head. Femoral version was calculated between the head and neck axis and either the PCA or TEA. Differences between sex and ethnicity were evaluated.
Results: The mean femoral anteversion was 12.7° ± 9.1° based on the PCA and 11.5° ± 7.9° based on the TEA (mean difference 1.2° ± 1.9°, $P < .001$). Males were less anteverted than females (9.8° ± 7.6° vs 13.5° ± 7.8°, $P < .001$). African Americans had less anteversion than other groups (8.1° ± 9.2° vs 11.5° ± 7.8°, $P =$ .04), while Asians were more anteverted than other groups (12.1° ± 9.0° vs 11.2° ± 7.3°, $P = .04$). These values were referenced on the TEA.
Conclusions: In this series of over 1500 femoral CT scans, the mean difference between anteversion measurements referencing the PCA and TEA was 1.2°. Native femoral version varied widely between gender and ethnic groups. Extreme femoral version, defined as <0° or >30°, was present in 11.8% of patients referencing the PCA.

Introduction

Optimizing combined anteversion in total hip arthroplasty (THA) is important for successful surgical and patient outcomes [1]. Appropriate anteversion confers stability and allows for the greatest impingement-free range of motion [1-3]. Combined anteversion depends on the positions of the acetabular cup and femoral stem [1]. While there are several techniques to measure the cup anteversion, there are no standardized measurement techniques for stem anteversion [4-7]. Even with the advent of robotics and navigation-based systems, these are targeted to optimize cup position with an assumed stem anteversion that cannot be precisely replicated intraoperatively [8-10]. Femoral stem anteversion can match or change the patient's native anteversion depending on component geometry and modularity, femoral morphology, and fixation method.

Native femoral anteversion can be calculated utilizing axial computerized tomography (CT) scans through the hip and knee [11,12]. Two lines in the patient's knee can be used as distal landmarks: the transepicondylar axis (TEA) [11,13] and the posterior condylar axis (PCA) [4,14]. Dorr et al. [4] studied the reliability of the stem anteversion measurement using the TEA or the PCA as a reference. He found that in over 100 implanted stems, both distal landmarks provided reliable measurements of stem anteversion. Several studies have studied the relationship between the PCA and the femoral head-neck axis to quantify anteversion of the native femur or an implanted stem [4,15,16]. In literature relating to total knee arthroplasty (TKA), other studies have compared the PCA to the TEA in relation to femoral component rotation, but these have not evaluated the distal femoral landmarks in relation to the proximal femur [17]. One study evaluated the anteversion of femoral stems after THA relative to the PCA vs TEA, but not native

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anteversion [16]. There is a paucity of literature on the use of the TEA in determining native anteversion. There is also a gap in the literature regarding variations in femoral anteversion across sex and ethnicity. Understanding native femoral anteversion and the possible patient factors that impact this value would allow treating surgeons to better anticipate each patient's specific needs for THA.

Thus, we evaluated a series of over 1500 CT scans of native hips and knees to measure femoral anteversion using the TEA and PCA. The primary aim of this study was to compare and correlate the values of femoral neck anteversion (FNA) using the TEA and PCA. The secondary aim of this study was to investigate the influence, if any, that sex or ethnicity had on femoral anteversion.

Material and methods

CT analysis

A series of 1507 CT scans (1004 patients) of native hips and knees were drawn from a database of patients that had CT scans done for preoperative planning prior to robotic THA and/or TKA. For the purposes of this study, age, sex, and ethnicity were recorded for each patient. Patients with prior TKA, prior THA, fracture, deformity, or dysplasia were excluded. Patients with bilateral CT scans had each side treated as an individual data point and combined for the results analysis.

The hip and knee were axially segmented. Precise bony landmarks were identified. In the knee, bony landmarks were the lateral epicondyle, medial epicondyle, the nadir of the posteromedial condyle, and the nadir of the posterolateral condyle. In the hip, bony landmarks were the center of the femoral neck and center of the femoral head. A line was drawn connecting the medial and lateral posterior condyles for the PCA. The medial and lateral epicondyles were defined as the sulcus of the most medial distal femur and the most prominent point on the lateral distal femur, respectively [13,18]. A line was drawn between the center of the femoral head bisecting the neck for the axis of the femoral head and neck. Analyses were performed on anonymized-CT data as part of the Stryker Orthopaedic Modeling and Analytics (SOMA) database [19,20]. All CT scans in the database had been obtained per local legal and regulatory requirements, which included ethics board approval and patient informed consent, where applicable. Automated morphometric measurements based on CT scans of the femur were performed with the Stryker Anatomy Analysis Tool (version 2021.1) (Stryker Corporation, Mahwah, NJ). Anatomical features that were required for assessing the femoral alignment during image acquisition and femoral version measurements were selected on a correspondent model and automatically mapped onto the CT scans in the database using statistical shape modeling technique [20]. This software methodology is similar to what is used for robotic THA in planning combined anteversion with a stem that largely matches the patient's proximal femoral anatomy. The software projects the femoral neck axis, TEA, and PCA all onto a plane normal to the proximal cancellous canal axis. Femoral neck version was calculated as the angle between the head and neck axis and either the PCA or TEA (Figs. 1 and 2). The measurements were conducted maintaining the same proximal reference, only changing the distal references. Demographic data are detailed in Table 1.

Statistical analysis

Patient demographics and recorded measurements were presented as means, standard deviations, and percentages. Femoral version measurements referencing the PCA and TEA were compared using a paired *t*-test. Femoral version measurements between sex and ethnic groups were compared using an unpaired *t*-test and analysis of variance. Significance was set at $P < .05$. All statistical analyses were performed using Stata 15.1 (StataCorp, College Station, TX).

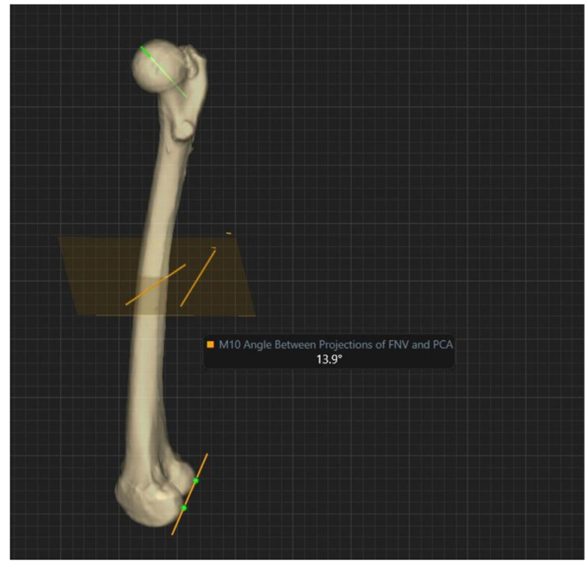

Figure 1. Example measurement of femoral version relative to the posterior condylar axis (PCA) using SOMA software.

Results

Posterior condylar axis vs transepicondylar axis

The mean anteversion relative to the PCA was 12.7° ± 9.1° whereas the mean anteversion relative to the TEA was 11.5° ± 7.9°. Anteversion relative to the PCA was 1.2° ± 1.9° greater than anteversion relative to the TEA ($P < .001$) (Table 2, Fig. 3). Correspondingly, the TEA was externally rotated relative to the PCA in 72% of CT scans, parallel in 16%, and internally rotated in 12% (Fig. 4). Relative to

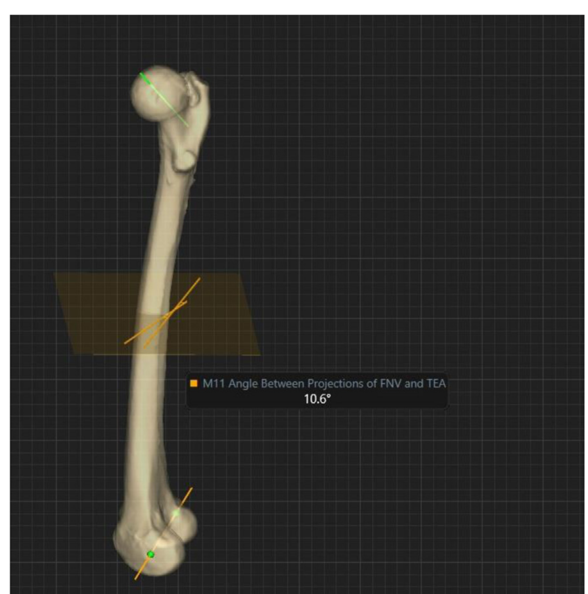

Figure 2. Example measurement of femoral version relative to the transepicondylar axis (TEA) using SOMA software.

Table 1
Demographics of the study sample.

Variable	All	Sex		Ethnicity			
		Male	Female	Caucasian	Asian	African American	Middle Eastern
Total	1507	820	687	999	459	23	26
Mean age	60.0	58.6	61.5	60.3	60.1	54.1	50.0
Mean height (cm)	167.8	173.8	161.5	170.1	161.1	167.1	172.2
Mean weight (kg)	71.4	77.3	65.4	75.6	59.6	72.4	80.7

the PCA, 3.7% of proximal femurs were anteverted more than 30°, 88.1% were anteverted less than 30°, and 8.1% were retroverted. Relative to the TEA, 1.9% of proximal femurs were anteverted more than 30°, 91.1% of proximal femurs were anteverted less than 30°, and 7.0% were retroverted. The range of anteversion measurements relative to the PCA was −23° to 45°. Similarly, the range of anteversion measurements relative to the TEA was −20° to 40°.

Differences across sex and ethnicity

Males were significantly less anteverted than females (9.8° ± 7.6° vs 13.5° ± 7.8°, $P < .001$). African Americans comprised a small portion of the overall sample (n = 23, 1.5%) but had less anteversion than other groups (8.1° ± 9.2° vs 11.5° ± 7.8°, $P = .04$). Asians were more anteverted than other groups (12.1° ± 9.0° vs 11.2° ± 7.3°, $P = .04$), and this difference was especially notable among women (15.5° ± 8.8° vs 12.6° ± 7.1°, $P < .001$). These values were referenced on the TEA.

Discussion

Native FNA varies widely in the general adult population [21]. The purpose of this study was to measure and compare femoral anteversion using the TEA vs PCA as the distal landmark. Our work demonstrated a mean difference of 1.2° in anteversion between the 2 distal femoral reference lines. This study also showed variations in mean femoral anteversion across demographic groups, with females having relatively more native anteversion than males and African Americans having relatively less anteversion than other racial groups.

Our results are consistent with several prior smaller studies. Dorr et al. [4], in their evaluation of 109 post-THA CT scans, demonstrated a mean difference in femoral anteversion of 2.0° between TEA and PCA references, with an excellent intraclass correlation coefficient of 0.994. In their evaluation of 91 post-THA CT scans, Castagnini et al. [16] found a mean difference of 5.3° between TEA and PCA anteversion measurements. Importantly, they also demonstrated that interobserver and intraobserver TEA measurements were more reliable than PCA measurements, suggesting that TEA should be preferred for measuring stem anteversion. In a larger study of 1215 hips prior to THA, Pierrepont et al. [21] found median femoral anteversion of 14.4° based on the PCA, compared to our sample with a mean anteversion of 12.7° (median 12.3°). In this study, however, the authors did not evaluate anteversion relative to the TEA.

Our study demonstrated that females had more native femoral anteversion than males. Relative to the PCA, females had a mean anteversion of 15.0° compared to males with 10.7° in our sample. These findings are similar to those of Pierrepont et al. [21], who found that anteversion in females was greater than that in males (16.0° vs 12.7°). Similarly, Hartel et al. [22], in an analysis of 1070 femoral CT scans, found that females had more anteversion than males (16.4° vs 12.1°).

We also found ethnic differences in femoral anteversion. Specifically, we found that Asian ethnicity was associated with 1.1° greater femoral anteversion than other ethnic groups, which is similar to that reported by Hartel et al. [22], who found that Asian ethnicity was associated with a mean 1.3° greater anteversion than Caucasians. Although African Americans comprised a small minority of our sample, they nonetheless demonstrated less anteversion than other ethnic groups. A study of 328 femoral CT scanograms by Koerner et al. [23] found no differences in mean femoral version between Caucasian, African American, and Hispanic patients.

In their sample, Pierrepont et al. [21] found that 14% of patients had extreme femoral version, defined as <0° or >30°. Our sample demonstrated that 11.8% of patients fell outside these bounds of extreme version. A wide variation in femoral anteversion is an important consideration when preoperative planning. It is helpful to have a good understanding of a patient's native anteversion

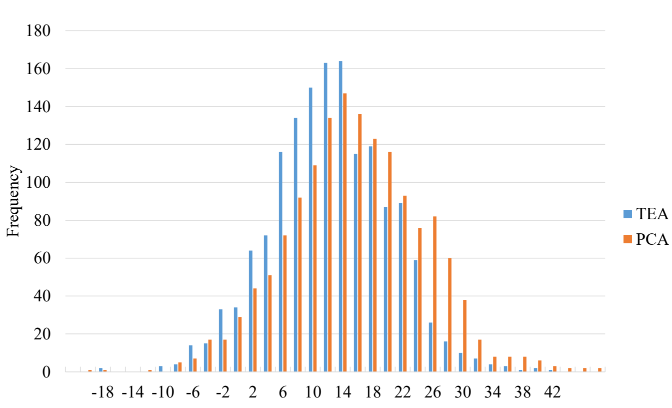

Figure 3. Native femoral version relative to the posterior condylar axis vs transepicondylar axis. PCA, posterior condylar axis; TEA, transepicondylar axis.

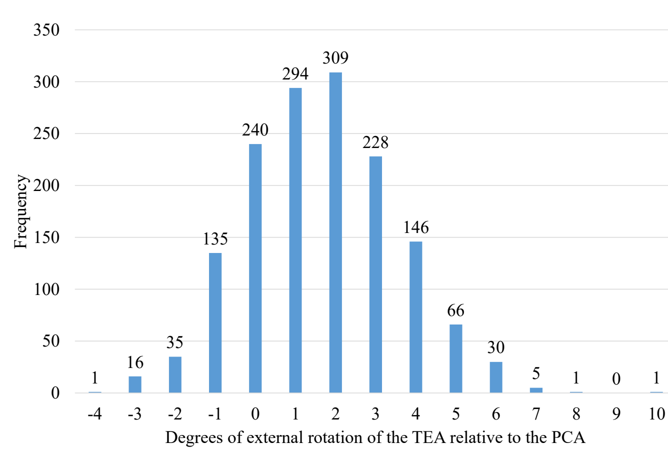

Figure 4. Orientation of the transepicondylar axis relative to the posterior condylar axis. PCA, posterior condylar axis; TEA, transepicondylar axis.

Table 2
Native femoral version measurements stratified by sex and ethnicity.

Variable	N	%	PCA		TEA		Mean difference	Paired *P* value	Overall *P* value
			Mean	SD	Mean	SD			
Total sample	1507	100	12.7	9.1	11.5	7.9	1.2	<.001	.001
Sex									<.001
Males	820	54%	10.7	8.6	9.8	7.6	0.9	<.001	
Females	686	46%	15.0	9.1	13.5	7.8	1.5	<.001	
Ethnicity									.048
Caucasian	999	66%	12.2	8.3	11.3	7.2	0.9	<.001	
Asian	459	30%	13.9	10.3	12.1	9.0	1.8	<.001	
African American	23	2%	8.7	10.6	8.1	9.2	0.6	.26	
Middle Eastern	26	2%	14.2	10.1	12.1	8.8	2.1	<.001	

Femoral version measurements are reported in degrees. Sex was missing for one CT. Paired *P* values refer to differences between PCA and TEA measurements within individuals. Overall *P* value refers to difference between groups based on TEA measurements.

preoperatively, as this can allow for appropriate implant selection. This is especially true in cases of “extreme version” which may require specialized modular implants [24,25].

The hip is only one joint in the lower extremity that contributes to the function of the lower limb. Rotation of the limb can occur through distal femoral internal or external rotation, tibial torsion, or dynamic pronosupination of the ankle. These factors can ultimately alter a component’s “functional version.” For example, Uemura et al. [15] found that the femur internally rotates 0.4° as femoral version increases every 1°. This is poorly described and understood in the literature and requires further investigation. Furthermore, Lewinnek’s “safe zone” (40° ± 10° of inclination and 15° ± 10° of anteversion) is considered the gold standard for acetabular cup positioning to avoid dislocation and impingement [26]. Recent literature has emphasized “combined version” where the position of the femoral component is just as important [8,27]. If the patient’s native anatomy has excessive femoral version, maintaining appropriate combined version should then necessitate compensatory retroversion of their acetabular component position.

In the senior author’s practice, femoral anteversion is routinely referenced against the TEA. This is because the TEA reflects the functional axis of the knee and is a more reliable reference point for femoral rotation [16,28]. Referencing the TEA as standard practice when discussing femoral anteversion would be helpful to ensure consistent measurements for both clinical care and research.

Our study has limitations. We did not assess reliability and repeatability of the anteversion measurements. All measurements were taken by a qualified engineer as part of a controlled process for planning a THA utilizing CTs. Every landmark used for the PCA, TEA, and FNA was verified by an engineer. Ethnicities were determined by patient face sheet demographics based on how the patient self-identified, which is subject to reporting bias. Some patients did not wish to be identified as any ethnicity. This was partially mitigated by the large size of the data set to include many of those that did identify. In addition, the sample was primarily composed of Caucasian and Asian patients, with relatively little representation from other ethnic groups. Finally, we did not compare anteversion variation within the same patient, but this may be an area of interest for future studies among patients with bilateral scans.

Conclusions

In this series of over 1500 femoral CT scans, the mean difference between anteversion measurements referencing the PCA and TEA was 1.2°. Native femoral version varied widely between gender and ethnic groups. Extreme femoral version, defined as <0° or >30°, was present in 11.8% of patients referencing the PCA.

Conflicts of interest

E.D. and D.G.L. report no conflicts of interest. T.M. is an employee of Stryker and has stock in Stryker. G.H.W. receives royalties and is a paid speaker for Stryker. He is a paid consultant for Stryker and Ethicon. He receives research support from Stryker. He has a committee appointment for the Eastern Orthopedic Association.

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CRediT authorship contribution statement

Elizabeth Davis: Writing – review & editing, Writing – original draft, Formal analysis. **Drake G. LeBrun:** Writing – original draft, Visualization, Formal analysis. **Thomas McCarthy:** Formal analysis, Data curation, Conceptualization. **Geoffrey H. Westrich:** Writing – review & editing, Formal analysis, Data curation, Conceptualization.

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