

# Three-Dimensional Morphological Analysis of the Femoral Neck Torsion Angle - An Anatomical Study.

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## Research article

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# Abstract

**Background:** The femoral neck torsion angle (FNTA) is a very important but often neglected parameter in assessments of the anatomical morphology of the femoral neck, and it is often confused with the femoral neck anteversion angle (FNAA) in the current literature. Currently, naked eye or two-dimensional literature (2D) visualization method was used in the literature that the measurement method reported, and the measurement parameters and details are not clearly defined. The objection of this research was to establish a three-dimensional (3D) method to measure the FNTA, and to analyse the anatomical and clinical significance of the results.

**Methods:** Computed tomography (CT) data of 200 patients who received a lower extremity CT angiography examination were selected for the three-dimensional CT (3D CT) reconstruction of bilateral femurs by using Mimics software. The 3D axis of the femoral neck was built, and the FNTAs of the isthmus and the basilar part were measured using the “inertia axes” method. SPSS software was used for statistical analyses.

**Results:** The difference in FNTA was statistically significant between the isthmus and the basilar part (isthmus  $30.58 \pm 8.90^\circ$  vs. basilar part  $23.79 \pm 3.98^\circ$ ;  $p < 0.01$ ). Significant differences in the FNTA were observed between the sexes (males  $31.99 \pm 9.25^\circ$  vs. females  $27.49 \pm 7.19^\circ$ ;  $p < 0.01$ ). The increase in FNTA from the basilar part to the isthmus was  $6.79 \pm 8.06^\circ$ , and the increase observed in men ( $7.87 \pm 8.57^\circ$ ) was larger than that in women ( $4.44 \pm 6.23^\circ$ ,  $p < 0.01$ ). However, no significant differences in the values were observed between sides. According to the correlation analysis, height exerted the greatest effect on the FNTA ( $r = 0.255$ ,  $p < 0.001$ ), and the stepwise linear regression analysis produced the following final regression model:  $Y = -27.685 + 35.134 \times \text{HEIGHT}$  ( $p < 0.001$ ,  $R^2 = 0.095$ ).

**Conclusions:** This study provides a new and reliable 3D method for measuring the FNTA. The method and results provide a methodological foundation and theoretical support for the research and development of internal fixation devices and configurations of the space for an implant designed to treat a femoral neck fracture. And, the optimal opening point of the femoral medullary cavity is recommended to be located at the posterior position of the top of the femoral neck cross-section during hip replacement.

## 1. Introduction

The anatomical morphology of the femoral neck plays an important role in the recognition and treatment of diseases around the hip joint. Many morphological parameters are closely related to the findings from clinical studies; and the important parameters include the femoral neck-shaft angle, femoral neck anteversion angle (FNAA) and so on<sup>[1-6]</sup>. However, the femoral neck torsion angle (FNTA) is an underappreciated anatomical parameter that was first proposed by Kate in 1976, who believed that the FNTA and the FNAA were two different angles. According to the study by Kate, the FNTA was defined as the angle formed by the femoral neck rotating around its axis, and the FNAA was the angle formed by the femoral neck rotating around the proximal femur axis<sup>[7]</sup>, but the measurement was performed using a

two-dimensional (2D) method. Zhu et al. suggested the use of a computed tomography (CT) reconstruction method to distinguish the FNTA from the FNAA in his study. In their study, the long axial plane of the femoral neck cross-section was initially created, which consisted of the long axis of the femoral neck cross-section and the femoral head center. Then, the FNTA was defined as the angle between the long axial plane of the femoral neck cross-section and the coronal plane of the proximal femur<sup>[8]</sup> (details are provided in Sect. 2.3 of the Methods). However, these methods did not define the position and direction of specific sections and the proximal coronal plane.

Relevant basic and clinical studies have found that the FNTA has important clinical significance in determining the spatial configuration of screws used for the internal fixation of femoral neck fractures and the screw hole design of the proximal femoral neck plate, as well as the proximal femoral medullary opening point and femoral prosthesis placement during hip joint replacement<sup>[6, 9–13]</sup>. Therefore, the accurate definition and measurement standard of the FNTA are very important. However, the FNTA was neglected clinically and many current studies often confuse the FNTA with the FNAA, which may easily lead to misunderstanding of the information presented in the studies, is not conducive to communication between scholars, and affects relevant basic and clinical studies<sup>[1, 6, 14]</sup>. Femoral shaft specimens and three-dimensional CT (3D-CT) data have been used by previous scholars to describe and measure the FNTA, but the specific location of the femoral neck cross-section was not described in these studies<sup>[7–9]</sup>.

In the present study, Mimics software (version 12.0, Materialise, Leuven, Belgium) was used to build a 3D structure, define the cross-section of femoral neck and the proximal coronal plane of femur, and establish a new and reliable 3D measurement method for the FNTA. The size of the FNTA at different cross-sections (femoral neck isthmus (FNI) and femoral neck basilar part (FNB)) in 200 patients was measured using this method, the size of FNTA was compared between the sexes, and the correlation between the parameters and age, height and weight were evaluated, thus providing a reference for further clinical applications and research.

## **2. Materials And Methods**

### **2.1 Research object**

CT data from 213 patients who received a lower extremity CT angiography examination in our hospital from December 2009 to December 2012 were collected. Two hundred of these patients who met the inclusion criteria were selected, including 137 men and 63 women. The age ranged from 50–85 years, with an average age of  $69.41 \pm 9.21$  years. Inclusion criteria were patients (1) older than 18 years of age (2) who did not present with femoral head necrosis, (3) severe hip osteoarthritis or rheumatoid arthritis, (4) a hip joint or femur deformity, (5) a history of hip or femur fractures, or (6) a history of hip or femur surgery.

This research project was approved by the ethics committee of our hospital. Because the study was a retrospective survey of medical imaging data and the anonymity of the patients' data was maintained,

informed consent was not required from patients.

## 2.2 Reconstruction of the 3D femoral model and establishment of the coordinate system

The slice thickness of CT scans analyzed in this study was 1.2 mm (Siemens AG, Erlangen, Germany). Notably, 3D models of the femur were reconstructed using Mimics software. A standardized coordinate system for each femoral model was constructed using the method described by Su et al. <sup>[15]</sup>, and the coronal, sagittal, and horizontal planes were defined to avoid interference from body position during the measurement of FNTA.

## 2.3 Definition of the morphological parameters (point, line, and plane)

The reconstructed femur model was input into the 3-Matic software (Materialise N.V., Belgium). First, the femur head was simulated as a closed sphere. The center of the sphere was defined as the center of the femur head, namely, point A <sup>[16]</sup>. Then, with point A as the center of the ball, the original sphere radius was increased by 2 mm to generate a solid ball that cut the femoral neck to obtain a corresponding section. This section was treated as a fitting circle, with the center defined as point B. Finally, the line connecting point A and point B was defined as the 3D axis of the femoral neck (Fig. 1 a-b).

A series of continuous vertical sections was established along the axis of the femoral neck with an interval of 1 mm between adjacent sections. The software automatically generated the area of each section, and the smallest cross-section of the three adjacent minimum cross-sections was defined as the FNI. The position of the anterior cross-section in which the femoral neck is connected to the greater or lesser trochanter was defined as the FNB. The “fit inertia axes” function in 3-Matic software was used to determine the long and short axes of the cross-sections of FNI and FNB. The method used to determine the long and short axes was defined as the “inertia axis” method (Fig. 1c-d).

At a proximal femur length of 25% and 35%, cross-sections of the femur were created after the intersection of the femur with the transverse plane <sup>[1]</sup>. Then, the inner connecting circles of these two cross-sections were created, and the centers of these two circles were obtained. The line through the centers was defined as the axis of the proximal femur, which was distinct from the axis of the femur. The latter was not a straight line but a curve due to the anterior and lateral arch of the femur <sup>[17]</sup>. Using 3-Matic software, a plane perpendicular to the coronal plane of the femur through these two centers was defined as plane A, and then a plane perpendicular to plane A was defined as plane B, which was also named as the coronal plane of the proximal femur (Fig. 2).

According to the method introduced by Zhu et al. <sup>[8]</sup>, the plane consisting of the long axis of the FNI cross-section and the center of the femoral head was defined as the long axial plane of the FNI, and the plane consisting of the long axis of the FNB cross-section and the femoral head center was defined as the long axial plane of the FNB (Fig. 3).

## 2.4 The measurement of the FNTA

The FNTAs of the isthmus and basilar part were defined as the angles between the long axial planes of FNI and FNB and the coronal plane of the proximal femur, which were measured directly using 3-Matic software (Fig. 4). The difference between the isthmus FNTA and the basilar FNTA was defined as the increase in the FNTA (iFNTA).

## 2.5 Reliability study

The intraclass correlation coefficient (ICC) was used to assess the reliability of the measurement method established in the present study. The sample size required in the reliability study was calculated using the formula reported by Walter and Eliasziw [18]. Subsequently, three observers and another observer made three repeated measurements of any 15 pairs of femur samples. Based on the suggestion proposed by Weir [19], a repeated-measures ANOVA was applied to avoid a significant difference in the results of the study. Two-way random and two-way fixed models were used to evaluate inter- and intraobserver reliability [20]. Fifteen paired samples were subjected to repeated FNTA measurements in a random order by one senior attending orthopedic doctor (RYZ) with a minimum of a 24-h interval between trials to evaluate the intraobserver reliability. The same measurements on the same specimens were performed in an independent manner and a random order to assess interobserver reliability by three other doctors (XYS, JXZ and JTL).

## 2.6 Statistical analysis

The measured data were analyzed using IBM SPSS Statistics software for Windows, Version 21.0 (IBM Corp., Armonk, NY, USA). Pearson's correlation coefficients and Spearman's rank correlation coefficients were calculated to analyze potential relationships between demographic data (age, height, weight, and BMI) and the FNTA. A stepwise linear regression model was applied to investigate the factors influencing the FNTA. Statistical significance was established at  $p < 0.05$ .

## 3. Results

The main characteristics (demographic data) of the participants and the differences between the sexes are summarized. The difference in ages between male ( $69.27 \pm 9.50$  years) and female ( $69.68 \pm 8.55$  years) patients was not statistically significant ( $p = 0.513$ ), but statistically significant differences in height (males  $1.68 \pm 0.06$  m vs. females  $1.59 \pm 0.06$  m;  $p < 0.01$ ), weight (males  $66.24 \pm 8.81$  kg vs. females  $62.32 \pm 9.80$  kg;  $p < 0.01$ ) and BMI (males  $23.39 \pm 2.70$  kg/m<sup>2</sup> vs. females  $24.77 \pm 3.54$  kg/m<sup>2</sup>;  $p < 0.01$ ) were observed.

High intraobserver and interobserver reliability ( $n = 30$ ) were observed, with ICC values of 0.989 and 0.996, respectively, and the mean squares within trials ranged from 0.131 to 0.179, with all  $p$  values greater than 0.05 (Table 1). A paired T-test was used to compare the FNTA between the isthmus and the basilar part, and the results are shown in Table 2. The FNTA of the isthmus was larger than the basilar part in different

groups, and the difference was statistically significant. The FNTA in all subjects was analyzed using a two-way ANOVA and the results are shown in Table 3. The FNTAs were significantly different between the sexes, with significantly greater values recorded in men than in women ( $p < 0.05$ ). No statistically significant differences were observed between sides or between the sexes and side interactions.

The results of the correlation analysis revealed positive correlations between the isthmus FNTA and iFNTA with height, and between the basilar FNTA and iFNTA with body weight; only the basilar FNTA was negatively correlated with BMI. All correlation coefficients are shown in Table 4. A stepwise linear regression analysis was conducted with age, height, weight, and BMI as independent variables to determine the most relevant factors that affected the FNTA. Ultimately, height exerted the greatest effect on the FNTA, and the final regression model of the isthmus FNTA was  $Y = -27.685 + 35.134 \times \text{HEIGHT}$  ( $p < 0.001$ ,  $R^2 = 0.095$ ).

## 4. Discussion

The FNTA and FNAA are completely different anatomical measurements<sup>[7-9]</sup>. First, the former is defined as the angle between the long axial plane of the femoral neck cross-section and the coronal plane of the proximal femur, and the latter is defined as the angle between the 3D axis of the femoral neck and the coronal plane of the femur. Second, the sizes of the two angles differ from each other. Third, the results reported in the literature using the 3D CT measurement method show that the FNAA is approximately 10°, while the FNTA is approximately 30°<sup>[7, 8]</sup>. Unfortunately, current studies often confuse the two angles<sup>[1, 6, 14]</sup>. In other words, the expression of the angles (femoral torsion angle and femoral neck torsion angle) is not standardized and consistent at present. For example, the expression of the FNTA was mentioned by Yin, Hartel, and Zhao, but in fact, it was actually the FNAA, according to the measurement method and results reported in their articles<sup>[1, 6, 14]</sup>.

Many methods have been established to define the femoral neck axis. In the early stage, the axis of the femoral neck was determined by the anteroposterior and lateral centerline of X-ray or two-dimensional CT, but both methods were affected by the femoral position during fluoroscopy, and the axis was ultimately two-dimensional<sup>[3, 4]</sup>. Nakanishi and Yin<sup>[5, 21]</sup> searched for the layers including both the femoral head and the femoral neck on coronal slices of 3D CT images, and they defined the connecting line between the femoral head center and the femoral neck isthmus center as the femoral neck axis. However, this method was also affected by the spatial position of the femur. Bonneau et al.<sup>[22]</sup> first proposed the concept of the 3D axis of the femoral neck. However, the reconstruction of the femoral neck medullary cavity is complicated because of the special distribution of bone trabeculae in the femoral neck (Fig. 4). In our study, the actual 3D axis of the femoral neck was generated using a 3D method. The shape of the femur is not a standard cylinder, the femoral trochanteric medullary cavity is irregular, and the femur length and curvature differ between men and women<sup>[17]</sup>. Therefore, the present study adopted the method introduced by Hartel et al.<sup>[1]</sup> to determine the axis of the proximal femur. Based on the traditional coronal plane of the femur, the coronal plane of the proximal femur was created using the method of

establishing a plane perpendicular to a specified plane through two points (details are provided in Sect. 2.3 of the Methods).

The FNTA of the isthmus that we measured was very similar to the values reported by Kate (30°) and Zhu (31.34 ± 2.08°), but these authors did not report the specific position of the femoral neck cross-section [7, 8]. Kate measured 1000 femur specimens in India, but the specific measurement method was not described in detail. Zhu et al. rebuilt the proximal femurs of 30 healthy adult volunteers and fitted the ellipse with the “concentric circle” method, but did not clearly define the position of the coronal plane of the proximal femur. Unfortunately, the lack of a definition in both of these articles significantly reduced the repeatability of their research methods. For the first time, the size of the FNTA at different positions (FNI and FNB) of the femoral neck was measured using 3-Matic software in the present study. The torsion of the femoral neck is not presumed to increase completely at one time from the FNB to FNI but may be increased gradually. The FNTAs at the FNI and FNB of the male patients are significantly greater than the female patients, which is of guiding significance for the treatment and posttreatment evaluation of patients of different sexes with femoral neck related diseases, such as the choice of the model of the internal fixation device. However, the FNTAs at FNI and FNB between left and right side were not significantly different, indicating that the anatomical morphology of the healthy side can be used as a reference for the treatment of the affected side in patients with femoral neck related diseases.

Three cannulated screws in parallel are currently still the first choice for femoral neck fracture fixation [13, 23]. The presence of a torsion angle directly affects the nailing point and screw configuration on the lateral wall of the greater trochanter. Therefore, the spatial distribution of the three screws should match the morphology of the transverse plane (including the FNTA) of the femoral neck isthmus as much as possible to abut the screws to the femoral neck cortex without iatrogenic penetration and to obtain the maximum occupancy effect of the three screws [9, 10, 13, 24]. Similarly, the screw hole design of the proximal femoral plate should refer to the FNTA. The attachment of the plate should be satisfactory while reducing the penetration rate of the femoral neck screw [25, 26]. Due to the presence of the FNTA in basilar part, the long axis of the FNB cross-section was not located in the coronal plane of the proximal femur. Thus, forward deviation of the opening was likely to occur in the operation, resulting in difficult prosthesis placement, proximal femoral splitting, and periprosthetic fracture. Postoperative complications such as anterior femoral pain and early loosening of the prosthesis are common. Therefore, the optimal opening point of the femoral medullary cavity during hip replacement should be the posterior position of the top of the femoral neck cross-section [10–12].

In the present study, correlation analyses and stepwise linear regression analyses were performed to determine the correlation between patient attributes and the FNTA as well as the degree of their influence. Height exerted the greatest effect on the isthmus FNTA and the iFNTA, which may be related to local muscle strength, as more muscle strength may be needed to coordinate the posture of a taller individual [27].

This study has one limitation: the patients in this study were relatively old. Thus, the reference range of the measured morphological parameters does not represent the overall population. Studies examining an expanded age group or comparing the data with findings obtained from other research centers are necessary to circumvent this limitation.

## 5. Conclusions

This study provides a new and repeatable 3D method for measuring the FNTA, and the FNTA of the isthmus is significantly greater than the FNTA of the basilar part. The size of the torsion angle of the neck isthmus of the femur is positively correlated with height and weight. The method and results of the measurement of the FNTA provide a methodological foundation and theoretical support for the research and development of internal fixation devices and configurations of the space for an implant to treat a femoral neck fracture. And, the optimal opening point of the femoral medullary cavity is recommended to be located at the posterior position of the top of the femoral neck cross-section during hip replacement.

## List Of Abbreviations

FNTA: Femoral Neck Torsion Angle; FNAA: Femoral Neck Anteversion Angle; 2D: Two-dimensional; 3D: Three-Dimensional; CT: Computed tomography; FNI: Femoral Neck Isthmus; FNB Femoral Neck Basilar Part; iFNTA: Increase in the FNTA; ICC: The intraclass correlation coefficient.

## Declarations

### Ethical approval and consent to participate

This research project was approved by the ethics committee of our hospital. Because the study was a retrospective survey of medical imaging data and the anonymity of the patients' data was maintained, informed consent was not required from patients.

### Consent for publication

Not applicable

### Availability of data and materials

Data and materials were accessed from the case system of our department.

### Competing interests

The authors have no conflicts of interest to declare.

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### Authors' contributions

PFT helped design the study. RYZ and XYS participated in conducting the experiments, performed the statistical evaluation of the data and determined their interpretation, and drafted and revised the manuscript. RYZ, JXZ and JTL contributed to conducting the experiments and drafted the manuscript. LCZ, XYS and JXZ supervised the study and revised the manuscript. All authors have read and approved the final version of the submitted manuscript.

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## Tables

**Table 1** Intraobserver and interobserver reliability of the measurements

Items	Intraobserver Reliability		Interobserver Reliability	
	ICC	95% CI	ICC	95% CI
Isthmus FNTA	0.993	0.989-0.996	0.995	0.991-0.998
Basilar FNTA	0.989	0.979-0.994	0.996	0.990-0.998
iFNTA#	0.991	0.983-0.996	0.995	0.989-0.998

# iFNTA: The difference between the isthmus FNTA and the basilar FNTA.

ICC: The intraclass correlation coefficient.

CI: Confidence interval.

**Table 2** Paired-sample T-test of the FNTA (mean  $\pm$  SD,  $^{\circ}$ )

	Total (400)	Males (137)	Females (63)	Left (200)	Right (200)
Isthmus FNTA	30.58 $\pm$ 8.90	31.99 $\pm$ 9.25	27.49 $\pm$ 7.19	30.06 $\pm$ 8.57	31.10 $\pm$ 9.21
Basilar FNTA	23.79 $\pm$ 3.98	24.13 $\pm$ 4.00	23.05 $\pm$ 3.84	23.49 $\pm$ 4.01	24.10 $\pm$ 3.92
T value	16.834	15.186	7.995	12.365	11.529
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

**Table 3** Differences in the FNTA (mean  $\pm$  SD,  $^{\circ}$ ) between sexes and sides (P1 value for sexes; P2 value for sides; P3 value for the interaction between sex and side)

Items	Males (137)		Females (63)		P1	P2	P3
	Left	Right	Left	Right			
Isthmus FNTA	31.37 $\pm$ 8.92	32.62 $\pm$ 9.56	27.20 $\pm$ 6.98	27.78 $\pm$ 7.44	< 0.001	0.328	0.722
Basilar FNTA	23.92 $\pm$ 3.97	24.34 $\pm$ 4.03	22.55 $\pm$ 3.99	22.55 $\pm$ 3.64	0.011	0.095	0.495
iFNTA <sup>#</sup>	7.45 $\pm$ 7.94	8.27 $\pm$ 9.18	4.65 $\pm$ 6.12	4.23 $\pm$ 6.38	< 0.001	0.812	0.466

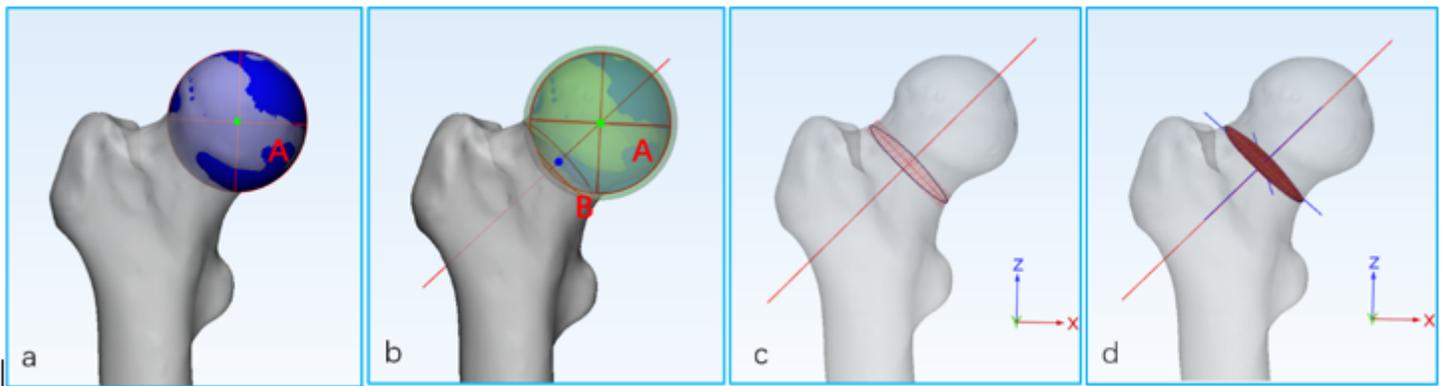
**Table 4** The correlation (r value) between morphological parameters of the femoral neck and physical properties

	Age	Height	Weight	BMI
Isthmus FNTA	-0.091	0.255**	0.061	-0.102*
Basilar FNTA	-0.018	0.050	-0.169**	-0.193**
iFNTA <sup>#</sup>	-0.115*	0.262**	0.186**	0.098

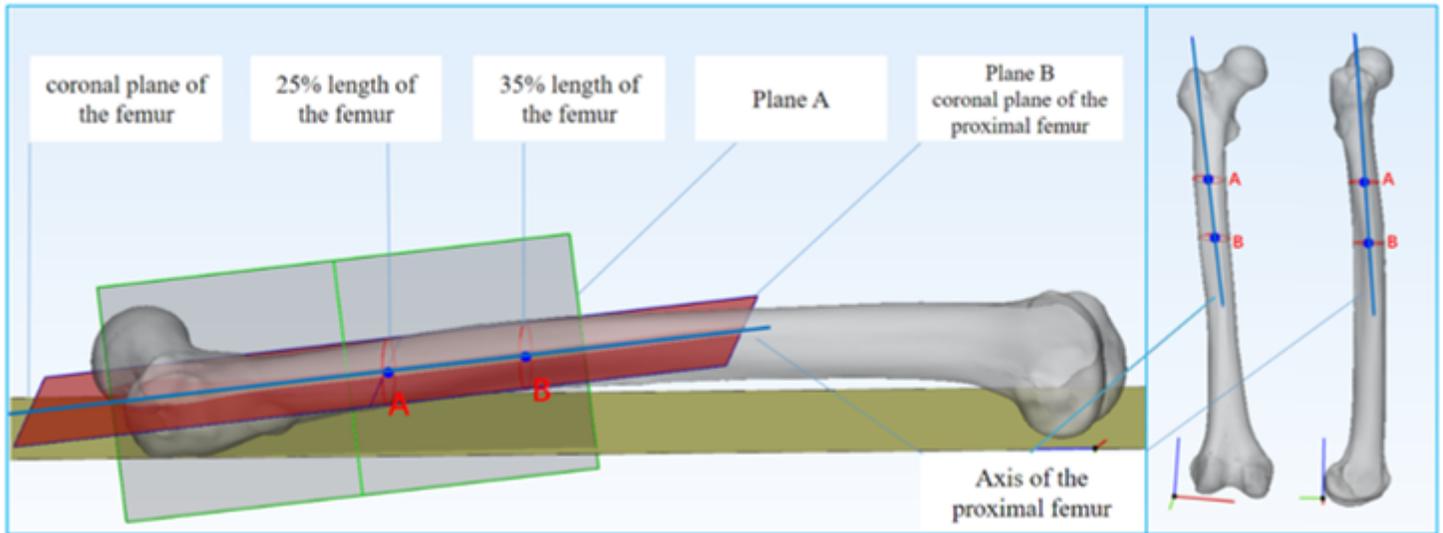
\* The correlation was significant at the level of 0.05 (two-tailed).

\*\* The correlation was significant at the level of 0.01 (two-tailed).

## Figures

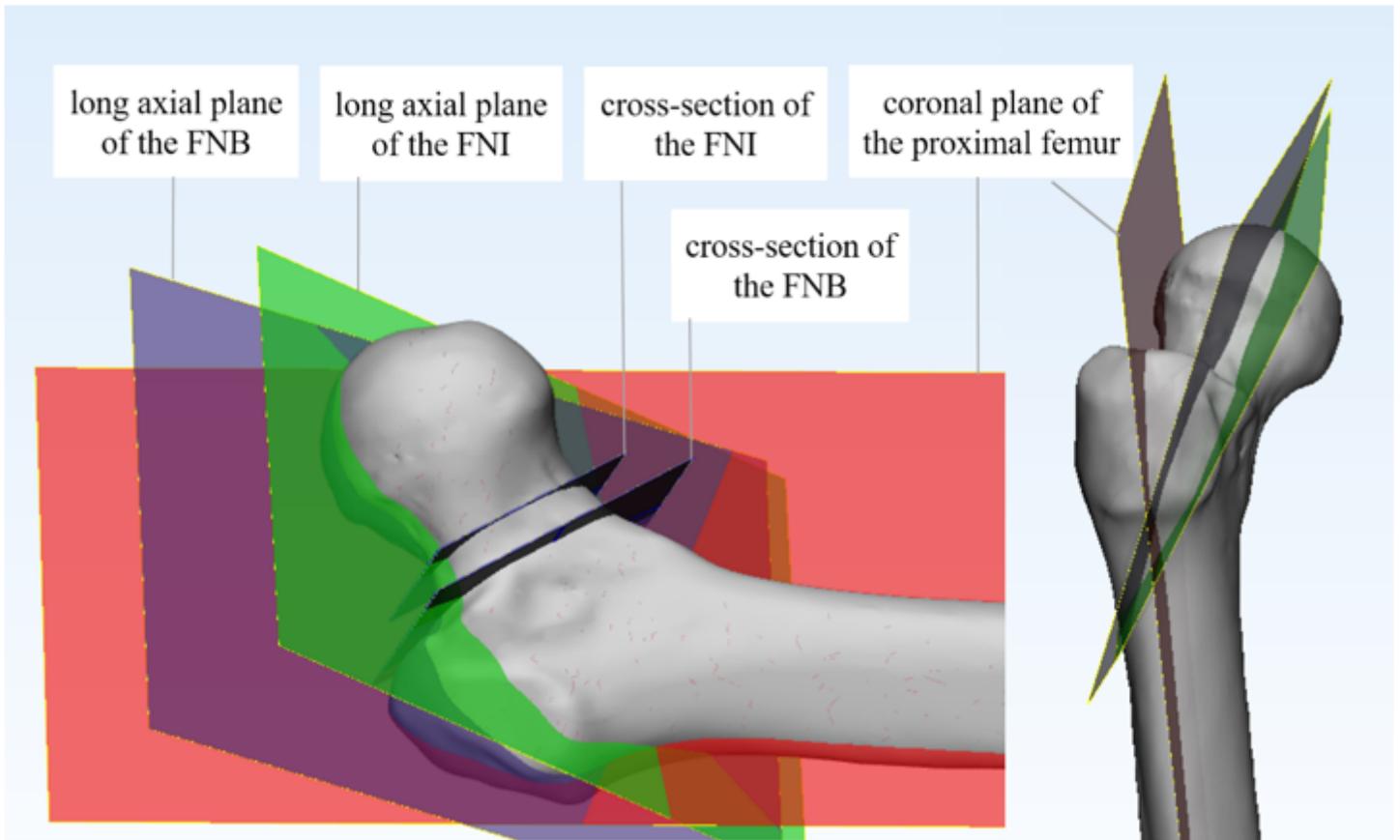
**Figure 1**

The method for determining the 3D axis of the femoral neck and the “inertia axis” method. a. The femur head was simulated as a closed sphere (blue) and the center of the sphere was defined as the center of the femur head, namely, point A. b. A concentric (point A) sphere (green) was generated by increasing the radius of the sphere fitted to the femoral head by 2 mm, which cut the femoral neck to obtain a corresponding cross-section. This cross-section was treated as a fitting circle, with the center defined as point B. Finally, the connecting line between point A and B was considered the 3D axis of the femoral neck. c. The 3D axis of the femoral neck and cross-section of the FNI. d. The cross-section of the FNI was extruded to a 0.5-mm depth, and then the inertia axes (three blue lines) of the extruded part of the cross-section of the FNI were established using the “fit inertia axes” function in 3-Matic software.



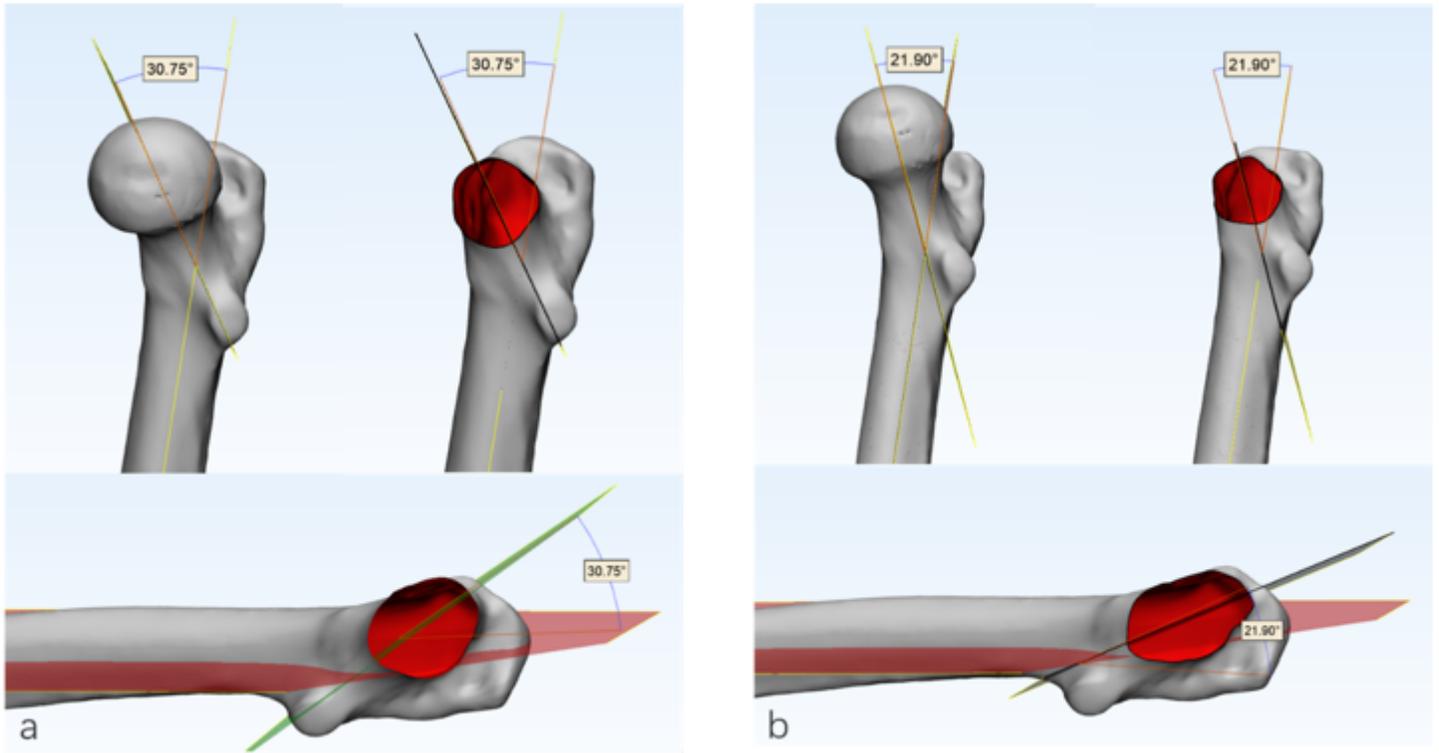
**Figure 2**

The method for determining the coronal plane and axis of the proximal femur The blue line through points A and B (the centers of the inner connecting circles of these two cross-sections represent 25% and 35% of the length of the proximal femur) was defined as the axis of the proximal femur. The gray plane perpendicular to the coronal plane (yellow) of the femur through points A and B was defined as Plane A, and then a plane perpendicular to Plane A was defined as Plane B (red), which was also designated the coronal plane of the proximal femur.



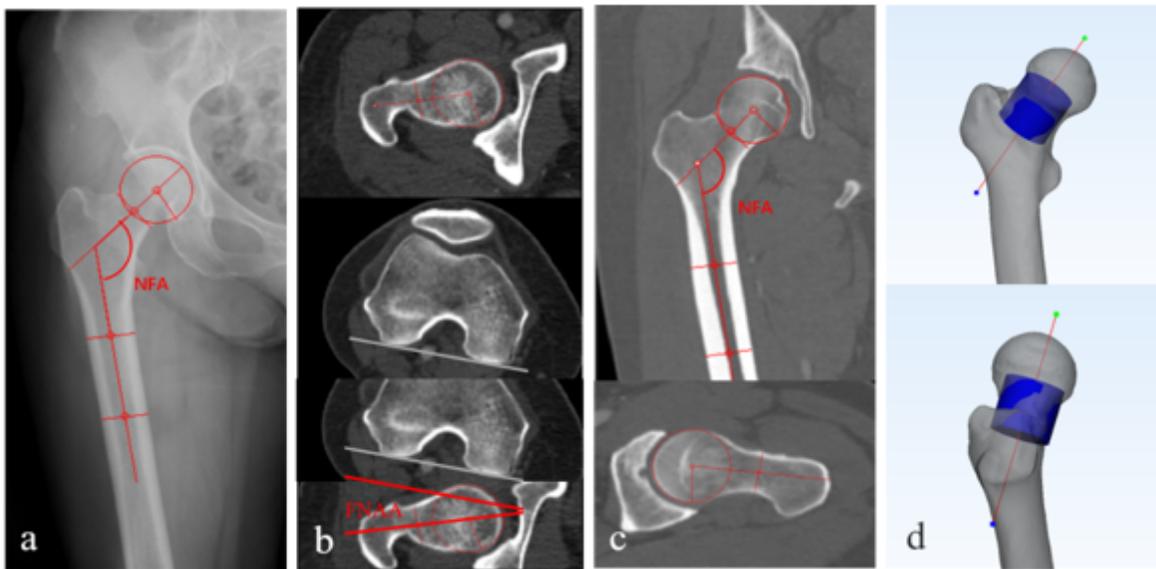
**Figure 3**

The long axial plane The red plane is the coronal plane of proximal femur, and the positions of the FNI and FNB are intersected by two black planes. The green plane is the long axial planes of the FNI, and the blue plane is the long axial plane of the FNB.



**Figure 4**

a. the FNTA of the isthmus (30.75°); b. the FNTA of the basilar part (21.90°)



**Figure 5**

The methods for defining the femoral neck axis a. The method described by Zhang YL et al. [4]. b. The method described by Morvan et al. [3]. c. The method reported by Nakanishi et al. [5]. d. The method reported by Bonneau N et al. [18].