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Measurement of the femoral neck anteversion angle using a three-dimensional reconstruction in the fixed coordinate system based on the basal anterior cortex of the femoral neck: an observational study

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Abstract

Purpose This study investigated the accessibility of 3D reconstruction in the fixed coordinate system(3D-R-FCS) based on the basal anterior cortex of the femoral neck in measuring the femoral neck anteversion angle (FNAA).

Methods CT and EOS examinations were performed on 40 femoral samples synthesized by Sawbone. Two evaluators were responsible for measurement of the FNAA based on four different methods, including EOS 3D reconstruction, 3D-R-FCS, Reikerås, and Murphy methods.

Results Measurement of the FNAA based on EOS, 3D-R-FCS based on the basal anterior cortex of the femoral neck, and the Reikerås and Murphy methods were 6.53°±4.28°, 7.08°±4.58°, 3.03°±4.44°, and 11.9°±4.91°, respectively. No statistical difference was detected for the FNAA measurements between EOS and the 3D-R-FCS based on the basal anterior cortex of the femoral neck ($P > 0.05$). However, a statistical difference was detected between the Reikerås and Murphy methods and EOS ($P < 0.05$). The value of the intraclass correlation coefficients (ICCs) for the 4 methods measured by evaluator A were 0.89, 0.99, 0.75, and 0.81, respectively, while the ICCs measured by evaluator B were 0.91, 0.98, 0.71, and 0.79, respectively. The correlation coefficients between the two evaluators were 0.89, 0.99, 0.75, and 0.83, respectively.

Conclusion The consistency of the scores for the FNAA measurement based on the 3D-R-FCS within and between the evaluators was the highest among the four methods and correlated well with the EOS measurement, which may potentially provide a more stable method for the measurement in clinical practice.

Clinical trial number Not applicable.

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Keywords Femoral anteversion angle, Anterior cortex, EOS, Fixed coordinate system, CT

Introduction

The femoral neck anteversion angle (FNAA) is the angle between the femoral neck and the femoral shaft, which indicates the degree of femoral torsion. The FNAA difference may generate the impact on the biomechanics of hip function through the alteration of factors, such as the length of the moment arm and joint loading [1]. The angle between the femoral neck and the femoral shaft is 12°–15° in the normal anatomic structure. In healthy individuals 30° is the maximum change in the angle, which maintains the stability and normal biomechanics of the hip joint. A previous study has shown that there is a relationship between an increased FNAA and micro-instability, while a decreased FNAA is prone to impingement [2]. Gait change related to the FNAA difference may result in the development of multiple musculoskeletal disorders, including osteoarthritis, hip pain and limitation of movement [3, 4]. For example, an extra large FNAA may lead to excessive valgus of the hip joint and increase the risk of wearing, while an extra small FNAA may lead to excessive varus and affect the stability of the hip joint [3, 4]. FNNA may be significantly observed in the patents with an arthritic hip or a spinopelvic misalignment [5]. Therefore, the FNAA measurement is of great significance in evaluating hip joint surgery, fractures, and hip joint deformities.

The methods for measuring the FNAA are diverse (X-rays, CT scans [6], MRI [7, 8] and EOS [9–11]) and the results can have huge differences. Biplanar X-ray generates unreliable results due to the spatial information, which causes uncertain patient positions. With the widespread application of CT, different methods of measurement are commonly used, including 2D methods, such as Reikerås and Murphy. However, the quality of such measurements is affected by multiple factors, such as the postural position and the femoral neck shaft angle, which barely meets the clinical requirements of surgery. CT scans have the benefit of a 3D measurement of femoral deformities. The latest EOS system reconstructs a 3D model of the femur, which can do a comprehensive imaging in three planes with decreasing patient radiation exposure [9–11]. A previous study showed that EOS generate images which are the closest to the true anatomical situation among the tested equipment [10]. Unfortunately, because a costly calibration instrument is required for the EOS system and occupies a large area, EOS has not been widely accepted [9–11].

There is no uniform standards for FNNA evaluation. This study chose EOS 3D reconstruction as the control method, and compare EOS 3D reconstruction, the Reikerås method, the Murphy method with 3D reconstruction in the fixed coordinate system (3D-R-FCS) based on the basal anterior cortex of the femoral neck in measuring FNAA. This study determined the accessibility of 3D-R-FCS based on the basal anterior cortex of the femoral neck in measuring FNAA and analyzed a stable and precise measuring method for orthopedic surgery that can be easily popularized.

Methods and materials

This was an observational study. Forty artificial femur model samples synthesized by Sawbone (FZ003; Enovao [Shanghai] Medical Teaching Development Industrial Co., LTD, China) were selected with 20 samples on each side. EOS and CT scan (Siemens 64-row Somatom Perspective;) parameters were as follows: EOS scan ([posteroanterior radiograph tube voltage, 50 kV; tube current, 50 mAs; speed of collection, 3]; [lateral radiograph tube voltage, 60 kV; tube current, 63 mAs; speed of collection, 3]); and CT scan (tube voltage, 80 kV; tube current, 15 mAs; spiral pitch, 0.95; layer thickness, 2 mm; and layer spacing, 2 mm). The ethical approval was waived by the Institution Review Board of Affiliated Haikou Hospital of Xiangya Medical College, Central South University because this study was proceeded on femoral samples synthesized by Sawbone without intervening with patients.

Measuring technique

EOS 3D measurement

The significant femoral biomarker was first identified using EOS sterEOS 3D software (midpoint of the femoral head, femoral neck, greater and lesser trochanters, incisura trochlearis, intercondylar eminence, and medial and lateral condyles; Fig. 1) and the FNAA was automatically generated after the 3D reconstruction.

3D reconstruction in the fixed coordinate system based on the basal anterior cortex of the femoral neck

After the CT scan and three-dimensional reconstruction were performed on the samples of artificial femur models synthesized by Sawbone, the surgical central axis (SCA) is vertical to the femoral neck obtained by a real cross-sectional CT scan. The images were captured from the top of the femoral head outward and downward. The layer thickness was 2 mm. The definition of SCA in this study was as follows: (A) the perpendicular bisector of the diameter connecting line of the upper and lower isthmus and the tangent of the coronal plane, which is parallel to the upper and lower isthmus of the femoral neck; (B) the sagittal plane, which is parallel to the anterior femoral neck; (C) the midpoint, which passes through the

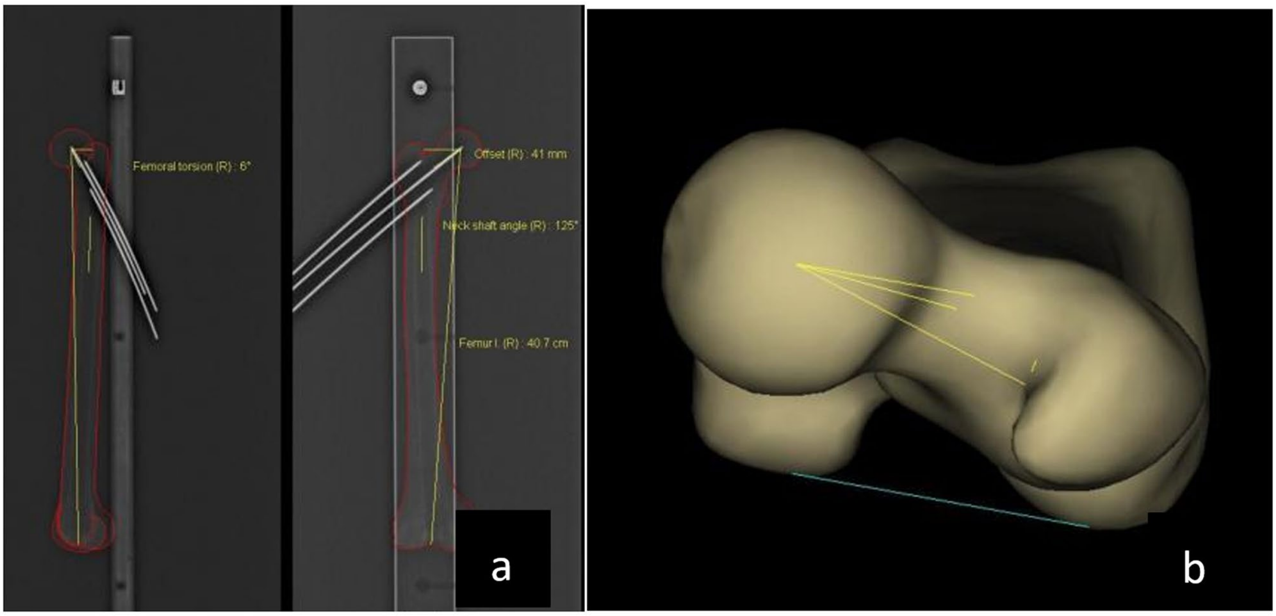

Fig. 1 FNAA measured by EOS. (**a**) The parameter was automatically generated by 3D reconstruction after the significant femoral biomarker was identified. (**b**) 3D figure of the FNAA

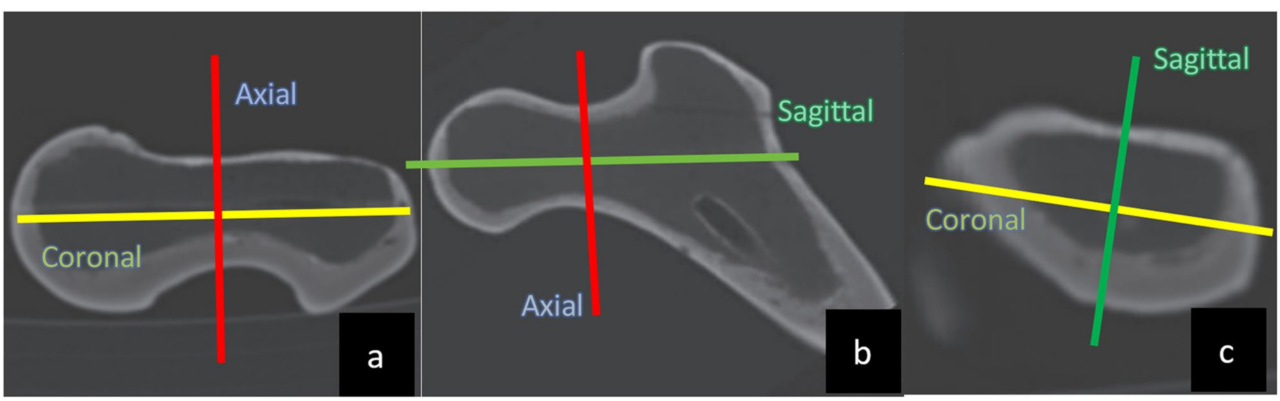

Fig. 2 Image of the standard axis position, sagittal plane, and coronal plane were constructed. (**a**) femoral neck standard sagittal position; (**b**) femoral neck standard coronal position; and (**c**) femoral neck standard axial position

upper and lower diameters, as well as the anteroposterior diameter in the area of the axial safety target; and (D) the SCA can be determined by the surgical technique during surgery. Similarly, the real images of the sagittal and coronal planes of the femoral neck were obtained (Fig. 2).

All CT images with axial positions were imported into the software, such as Bridge and Photoshop CC, and two layers of the images were overlaid in situ sequentially. The non-public areas were removed and the intersection of images was reserved (Figure 3a-c). After all the relevant CT images were overlaid, the public area on all the CT images of the femoral neck axial position were obtained, which indicates the safety target area of the screw placement channel axial position. AD at the bottom edge of the triangle safety area was taken as the parallel line of the Y-axis and the circumscribed rectangular ABCD was drawn with the center (O) as the origin and the plane rectangular coordinate system (YOZ) was constructed(Figure 3d) as well as the space rectangular coordinate system (XOYZ) [12]. The distal end of Sawbone artificial femur model was scanned by CT. The final line between the internal and external ankles defined the ankle axis. The X-axis is parallel to the central axis. The angle between the X-axis and the ankle axis was defined as FNAA. The measurement included the angle between the X-axis and the condyles axis was the FNAA.

Reikerås method

The FNAA value was determined by three overlaid CT images (Fig. 4). The neck axial was determined by the connecting lines of the midpoints in the narrowest area between the femoral head and femoral neck. The femur

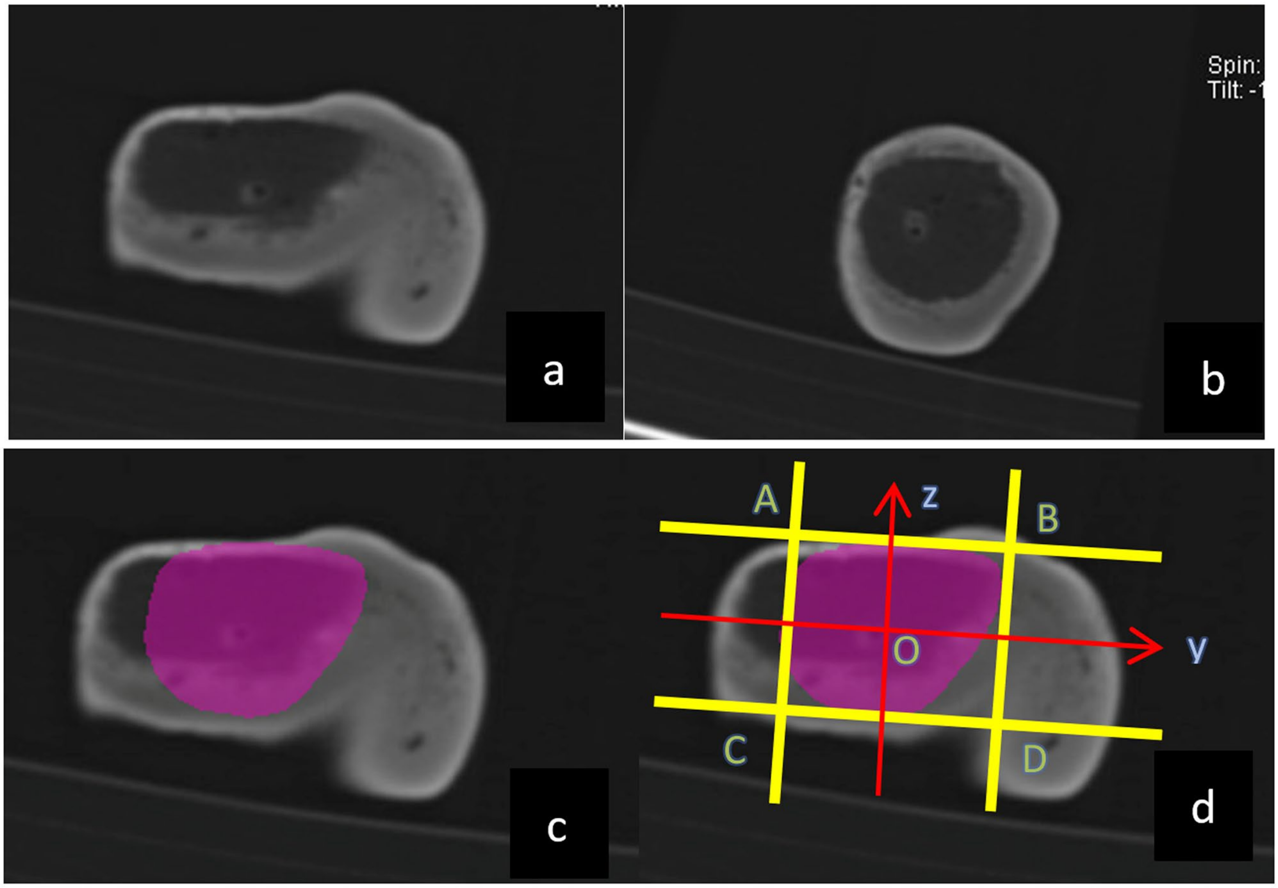

Fig. 3 Construction of the safety target area and the coordinate system. (**a**) the first layer of the femoral neck image; (**b**) the second layer of the femoral neck image; (**c**) the ratio remained unchanged, the first and second layers of the images were overlaid in situ, and the red part was the public area; (**d**) construction of the coordinate system by taking AB at the bottom edge of the triangle safety area to be the parallel line of the Y-axis and drawing the circumscribed rectangular ABCD with its center (O) as the origin, then constructing the rectangular coordinate system

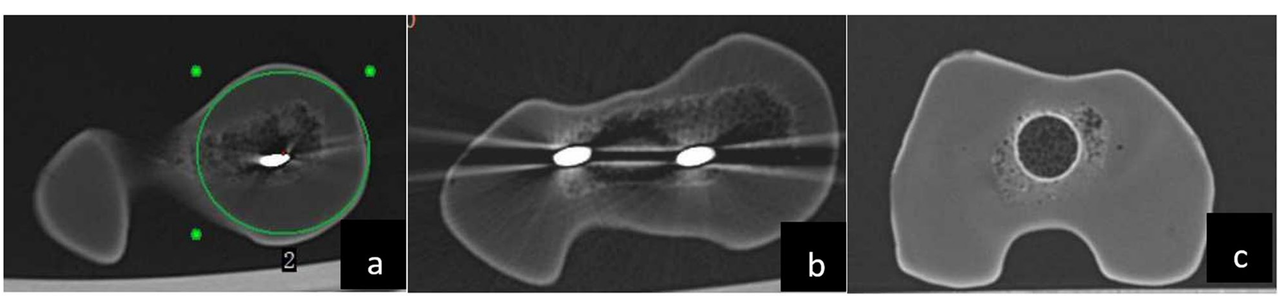

Fig. 4 The FNAA measured by the Reikerås method (**a**) the center layer of the femoral head; (**b**) the narrowest layer of the femoral head; and (**c**) the layer of the lowest part of the medial and lateral condyles of the femur

condyles were scanned and the condyles axial was defined as the selected connecting line in the final part between the medial and lateral condyles. The angle between the neck axial and the condyles axis was the FNAA.

Murphy method

FNAA was determined by three overlaid CT images (Fig. 5). In this method, two images were overlaid and the neck axis was determined on both ends of the femoral head and neck. The H point was determined by the femoral head on one tangent plane, which was the midpoint of the femoral head. The O point was determined by the basilar part of the femoral neck on the other tangent plane, which was the origin of the femoral neck. The neck axis was determined by the connecting lines of H and O. The head and neck axis of the anteversion angle was determined by the two overlaid CT images. The largest CT layer image of the two femur condyles was selected to

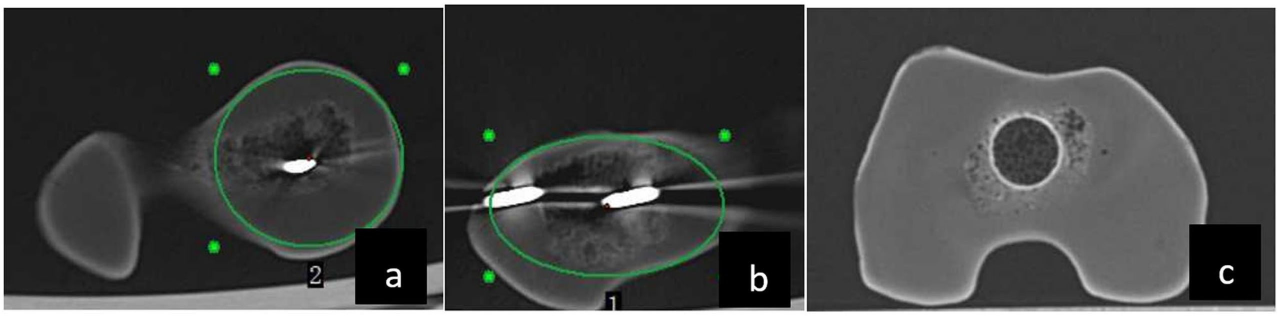

Fig. 5 The FNAA measured by the Murphy method. (**a**) the center layer of the femoral head; (**b**) the basilar part of the femoral neck; and (**c**) the layer of the lowest part of the medial and lateral femur condyles

Table 1 FNAA measurement results

EOS measurement	3D reconstruction in the fixed coordinate system based on the basal anterior cortex of the femoral neck	Reikerås	Murphy	P1	P2	P3
6.53 ± 4.28	7.08 ± 4.58	3.03 ± 4.44	11.9 ± 4.91	0.58	0.01	0.01

P1: Comparison between the 3D reconstruction in the fixed coordinate system based on the basal anterior cortex of the femoral neck and EOS

P2: Comparison between the Reikerås method and EOS

P3: Comparison between the Murphy method and EOS

be the tangent of the posterior edge of both condyles. The angle between the head and neck axis and the tangent was the anteversion angle.

Statistical analysis

The measuring data were analyzed using IBM SPSS Statistics software for Windows (version 26.0; IBM Corp., Armonk, NY, USA). Student's t-test was used to compare the statistical difference among the four methods. Statistical significance was defined as a $P < 0.05$. The reliability of the methods of measurement was calculated and analyzed within and between the evaluators, which was expressed by the intraclass correlation coefficients (ICCs). The ICC value was defined based on the following criteria: reliability was considered high at an ICC > 0.75; an ICC between 0.75 and 0.40 was considered moderate; and an ICC < 0.40 was considered low. The repeated Pearson correlation analysis was used to evaluate relevance among the methods of measuring femoral torsion. Reliability was defined by five categories: poor ($R \leq 0.3$); average ($R = 0.31–0.5$); moderate ($R = 0.51–0.6$); strong ($R = 0.61–0.8$); or very strong ($R = 0.81–1$).

Results

The FNAA measurement results based on EOS, 3D-R-FCS based on the basal anterior cortex of the femoral neck, and Reikerås and Murphy methods were 6.53°±4.28°, 7.08°±4.58°, 3.03°±4.44°, and 11.9°±4.91°, respectively. No statistical difference was detected in the FNAA measurements between EOS and the 3D-R-FCS based on the basal anterior cortex of the femoral neck. However, a statistical difference was detected between the Reikerås and Murphy methods and EOS. The angle measured by the Reikerås method was 3.5° lower than EOS and the angle measured between the Murphy method was 5.4° higher than that measured with EOS (Table 1).

Table 2 Reliability of the evaluators among the four methods for measuring the FNAA

Method of measurement	Evaluator A ICC	Evaluator B ICC	ICC between Evaluator A and B
EOS	0.89	0.91	0.89
3D reconstruction in the fixed coordinate system based on the basal anterior cortex of the femoral neck	0.99	0.98	0.99
Reikerås method	0.75	0.71	0.75
Murphy method	0.81	0.79	0.83

Reliability of the four FNAA measurement methods within and between the evaluators was compared

The ICCs between the first and second FNAA measurements for the four methods, including EOS, 3D-R-FCS based on the basal anterior cortex of the femoral neck, and the Reikerås and Murphy methods for evaluator A were 0.89, 0.99, 0.75, and 0.81, respectively. The ICCs between the first and second FNAA measurements for evaluator B were 0.91, 0.98, 0.71, and 0.79, respectively. The correlation coefficients between the two evaluators were 0.89, 0.99, 0.75, and 0.83, respectively (Table 2).

Pearson correlation analysis

The correlation between EOS and the 3D-R-FCS based on the basal anterior cortex of the femoral neck was strong. However, the correlation decreased when compared to the Reikerås and Murphy methods ($R = 0.96$, 0.87, and 0.80, respectively). The correlation equations were $y = 1.0458x + 0.2586$, $y = 0.9749x - 3.3319$, and $y = 1.0279x + 5.1967$, respectively (Fig. 6).

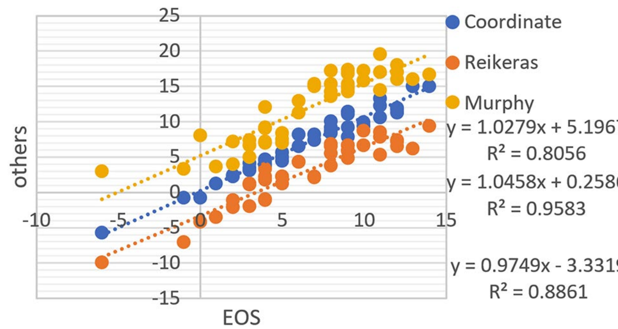

Fig. 6 The correlation among the methods expressed by a scatter plot. The correlation between EOS and the 3D reconstruction in the fixed coordinate system based on the basal anterior cortex of the femoral neck was stronger compared to the Reikerås and Murphy methods

Discussion

FNAA is significant in clinical practice. No statistical difference was detected in the FNAA results between the methods based on 3D-R-FCS and EOS ($P = 0.58$). However, a statistical difference was detected between the Reikerås and Murphy methods and EOS ($P < 0.01$). The mean value of the angle measured by the Reikerås method was 3.5° lower than EOS. This result may be accounted for by the following reasons: first, the femoral head is not a real spherical structure and may lead to incomplete superimposition between the midpoint and central axis of femoral head under the circumstance of femoral neck torsion; and second, torsion of the proximal femur is greater than the formal head and the decrease in the midpoint of the proximal femur is greater than the midpoint of the femoral head, which may lead to a greater FNAA when compared to the angle without torsion. Therefore, the FNAA using the Reikerås method will be smaller. The mean value of the angle measured by the Murphy method was 5.4° higher than EOS. We speculated that the decrease in the midpoint of the proximal femur was greater than the midpoint of the central axis. This situation may lead to a greater FNAA measured by Murphy method when compared to the central axis. However, both two methods have dismissed the fact that the femoral neck has torsion other than anteversion and the impact of the torsion angle on the central axis was neglected. Due to the notable difference in femoral neck torsion between the isthmus and basilar region, a significant difference may be caused under different methods of measurement. A study by Van Fraeyenhove et al. showed that Murphy method overestimates anteversion whereas it underestimates the anteversion compared to 3D evaluation [13]. Furthermore, the height and gender of the individual are key factors influencing torsion [13–15]. In this study the 3D reconstruction was adopted using the intersection method of the cross-sectional CT image to obtain the safety target area of the individualized cross-sectional plane of the femoral neck screw placement channel, which was oriented and quantified by the SawBone model. The results indicated that the safety target area was in an oblique rounded quadrilateral shape and the anterior bottom edge was overlaid with the flat anterior cortex of the femoral neck basilar region, which could serve as the reference mark and the surgical benchmark of the standardized fixed coordinate system construction [12, 16].

An analysis of the score consistency for the four methods of measuring the FNAA within and between the evaluators demonstrated that the consistency of the scores for the FNAA measurement based on the 3D-R-FCS within and between the evaluators was the highest among the four methods (the ICCs of evaluators A, B, and between both were 0.99, 0.98, and 0.99, respectively), which was much higher than the other methods. In this study the measurement was based on the basal anterior cortex of the femoral neck. The standardized fixed coordinate system was constructed based on the safety target area and the anterior bottom edge without manual operation. The fixed central axis not only helps to avoid the impact of femoral torsion on the anteversion angle before measurement but also shares a high degree of consistency and repeatability [12, 16]. The Reikerås method is based on three images, which requires manual operation for measurement of the femoral head and femoral isthmus midpoints, leading to huge variability. Different operators may have deviations on the measuring results. Similarly, the Murphy method requires manual operation for measurement of the femoral head and femoral basilar midpoints, which leads to huge variability and is why the ICC scores between the evaluators were low under the Reikerås and Murphy methods. This variability was also demonstrated by Zhang et al. [17] The significant femoral biomarker was first identified by EOS sterEOS 3D software (midpoint of the femoral head, femoral neck, greater and lesser trochanters, incisura trochlearis, intercondylar eminence, and medial and lateral condyles) and the FNAA was automatically generated after the 3D reconstruction. The anatomic landmarks are identified manually in the process. Although a result deviation results from the manual operation, the impact still exists. Therefore, analysis of the score consistency within and between the evaluators demonstrated that the EOS scores were lower than the method based on the 3D-R-FCS but still higher than the Reikerås and Murphy methods. Additionally, the Pearson correlation analysis showed that the R value for the correlation between EOS and the 3D-R-FCS, and Reikerås and Murphy methods were 0.96, 0.87, and 0.80, respectively, which indicated that the FNAA automatically generated by the 3D reconstruction and the EOS 3D software had a good correlation.

The results indicated that the 3D-R-FCS was superior to the Reikerås and Murphy methods and the difference between the results and EOS was small, which may be a good alternative to EOS and a good method for addressing the insufficient popularity of EOS. The 3D-R-FCS might be helpful for reducing the result deviation caused by manual operation. Fixation of the central axis and consistency of the scores between the evaluators were comparably high, which may become the method for measuring FNAA depending on the convenience, high accessibility, and high stability.

There were a few limitations in this study. First, the femoral samples were synthesized by Sawbone, which have not been put into clinical practice in the human body. Second, the sample size was relatively small. Third, the impact of the femoral torsion on the central axis was analyzed but neither the angle of the torsion was measured nor was the correlation between the torsion angle and the FNAA analyzed. Fourth, there are several methods for 3D reconstruction, it may be a limitation to choose the current methods in this study. Finally, the 2D reconstructions have the limitation of femur flexion when lying on the CT scan table (notably flexion contracture in cases of osteoarthritis) in the evaluation of human body. The results of this study may have variations compared to clinical studies.

Conclusion

The FNAA measurement based on 3D reconstruction in the fixed coordinate system was shown to be superior to the Reikerås and Murphy methods. There was a small deviation from the results of EOS. Furthermore, the consistency scores within and between the evaluators was the highest among the four methods and had a good correlation with the EOS measurement. However, the results were measured based on Sawbones, which may need further validations in clinical cases.

Abbreviations

FNAA	Femoral Neck Anteversion Angle
ICCs	Intraclass Correlation Coefficients
SCA	Surgical Central Axis

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Not applicable.

Author contributions

Conceptualization: Ruibao YangData curation: Guibin Han, Jie Lin Formal analysis: Ruibao Yang Funding acquisition: Guangliang Jiang Investigation: Ruibao Yang, Guibin Han, Jie Lin Methodology: Guangliang Jiang Resources: Yingsheng Deng Supervision: Guangliang Jiang Writing - original draft: Ruibao Yang Writing - review & editing: Ruibao Yang, Guangliang Jiang.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The ethical approval was waived by the Institution Review Board of Affiliated Haikou Hospital of Xiangya Medical College, Central South University because this study was proceeded on femoral samples synthesized by Sawbone without intervening with patients.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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