Midcortical-line is More Reliable than T-line in Predicting Stem Anteversion in Patients with Developmental Hip Dysplasia after Total Hip Arthroplasty

Ziang Jiang
School of Biomedical Engineering and Med-X Research Institute, Shanghai Jiao Tong University
Rongshan Cheng
School of Biomedical Engineering and Med-X Research Institute, Shanghai Jiao Tong University
Willem Alex Kernkamp
Leiden University Medical Center
Chunjie Xia
School of Biomedical Engineering and Med-X Research Institute, Shanghai Jiao Tong University
Junjie Liang
Guigang City People's Hospital
Liao Wang
Department of Orthopaedic Surgery, Shanghai Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine
Tsung-Yuan Tsai (tytsai@sjtu.edu.cn)
School of Biomedical Engineering and Med-X Research Institute, Shanghai Jiao Tong University

Research Article

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Abstract

Background: Precise preoperative planning improves postoperative outcomes in total hip arthroplasty (THA), especially in developmental dysplasia of the hip (DDH) cases. Previous studies used the T-line and midcortical-line (at different femoral neck levels) as preoperative landmarks to predict postoperative stem anteversion (PSA). However, the most reliable landmark in predicting PSA in DDH patients remains unclear. This study aimed to investigate whether the midcortical-line or T-line is more reliable in predicting PSA, and to find the optimal femoral neck level for predicting PSA in DDH patients.

Methods: Pre- and postoperative Computed Tomography (CT) scans of 28 hips in 21 DDH patients who received THA were obtained for three-dimensional femoral models. On the preoperative CT scan, the anteversion of the midcortical-line on the axial cross-sectional plane images (AM-CT), the anteversion of the midcortical-line from 3D models (AM-3D), and the T-line from 3D models (AT-3D) were measured at simulated osteotomy planes at 5 and 10 mm heights proximal to the base of the lesser trochanter. The correlation between the preoperative femoral anteversion (AM-CT, AM-3D, AT-3D) and the PSA was assessed to evaluate the prediction accuracy.

Results: The correlations between the AM-CT and the PSA were 0.86 (mean difference (MD) = 1.9o) and 0.92 (MD = -3.0o) at 5 and 10 mm height, respectively. The correlation between the AM-3D and the PSA were 0.72 (MD = -8.0o) and 0.61 (MD = -9.3o) at 5 and 10 mm cutting height. The AT-3D was significantly greater (MD = 19.0o, 11.3o) than the PSA (p-value < 0.01 and p-value = 0.010) at both 5 mm and 10 mm cutting height.

Conclusions: The AM-CT at 10 mm height had a strong correlation with the PSA and was more reliable in predicting the PSA when compared with the AM-3D and the AT-3D in DDH patients.

Introduction

Appropriate postoperative stem anteversion (PSA) in total hip arthroplasty (THA) is critical to achieving implant stability, optimal range of motion (ROM), and avoiding impingement [1–13]. The combined anteversion technique, which considers the sum of acetabular cup anteversion and femoral anteversion, has been clinically proven to prevent implant impingement if controlled in a safe zone of 25°-50° [8, 14–16]. Among implant positions, the stem anteversion is more challenging to control or predict; hence the conception of the "femur-first" technique [14, 17] was developed. The range of cup anteversion was calculated according to the intraoperative stem anteversion and the safe zone. Therefore, the prediction of PSA plays a decisive role in the implantation target of the acetabular cup, which can optimize the combined anteversion of the preoperative planning process [2]. Accurate predictions of the PSA may improve surgical outcomes after THA.

Few studies have used anatomical landmarks of medical images to predict PSA before THA. Suh et al. [18] reported that the midcortical-line is compatible with the true femoral anteversion using a single slice of CT. However, Tsukeoka et al. [19] reconstructed 3D hip models from CT and demonstrated that the stem tended to retroversion compared with the midcortical-line on the cut surface of the femoral neck. These differences in the reliability of the midcortical-line could attribute to different methodologies. Also, the lesser trochanter could be used to estimate femoral anteversion of the femoral component intraoperatively with a mean difference of less than 5° [20]. However, it is difficult to evaluate the version of the lesser trochanter using a surgical incision other than the posterior approach. The T-line method connects the trochanteric fossa and the inferior margins on the cut surface. During total hip arthroplasty, it reproduces the native femoral anteversion in osteoarthritis patients [19]. 3D analyses are thought to better simulate the intraoperative view before THA. Detailed 3D information may be particularly helpful in complex preoperative planning in patients with developmental dysplasia of the hip (DDH) [11, 19, 21, 22]. However, 3D analysis requires intensive work and is therefore not practical in daily practice. The relatively convenient use of CT images for PSA prediction has also not been evaluated for its efficiency in DDH patients.

Furthermore, the level of the CT images selected in predicting the PSA also affected the accuracy. Yu et al. [13] showed that AM-CT, which selected the CT images at a proximal level, accurately predicted PSA for Crowe type II/III DDH patients with a posterolateral approach and “acetabular-first” technique. Tsukeoka et al. [21] simulated the osteotomy process on 3D femoral models, which showed that the AT-3D at 5 mm cutting height proximal to the lesser trochanter reproduced the NFA better than that at 10 mm. However, the effect of T-line use in predicting the PSA remains unknown. The best level of the femoral neck osteotomy for DDH patients is still controversial. Therefore, the optimal femoral neck level for PSA prediction in DDH patients requires further investigation.

This study aimed to investigate: (1) whether the midcortical-line or the T-line was more reliable in predicting the PSA in DDH patients; (2) to find the optimal femoral neck level at which the T-line and midcortical-line could better predict PSA in DDH patients.

Materials & Methods

Patient demographics

The Internal Review Board approved this study. 28 hips were enrolled in this study retrospectively. The inclusion criteria were: patients with DDH Crowe grade I to IV who had undergone cementless THA and had received pre-and postoperative femoral CT scans between May 2013 and September 2015. The exclusion criteria were: patients who underwent an osteotomy lower than the lesser trochanter level during surgery, patients without femoral head or neck, patients who had prior hip surgery, patients who missed the pre-operative or postoperative lower limb CT images, and patients who had a surgical complication of dislocation or component subluxation on the implanted hip. A total of 17 hips were Crowe type I (< 50% subluxation); 6 Crowe type II/ III (50–75% /75–100% subluxation); and 5 Crowe type IV (> 100% subluxation) [23] (Table 1). According to the guideline of Crowe classification, the dysplasia with the lateral center-edge angle (LCEA) of the participants was less than 20° measured from an AP radiograph.

Table 1
Characteristics in DDH patients

Parameters	Mean ± SD
Age	64.5 ± 8.9
Weight (kg)	64.0 ± 10.2
Height (m)	1.6 ± 0.1
BMI (kg/m^2)	24.7 ± 3.1

Surgical procedure

All DDH hips received cementless THA prostheses (Stryker Secur-Fit, Mahwah, New Jersey, USA; DePuy SUMMIT, Warsaw, IN, USA) with metaphyseal fit stems by the same experienced arthroplasty surgeon (Z.Z.) using a posterolateral approach to expose the capsule, the acetabulum, and the proximal femur. Intraoperatively, the femoral stem was implanted using the "femur-first" technique [14, 17], in combination with the evaluation of the medullary cavity, femoral geometry, acetabular position [24], and experience.

Measurements based on CTs

The pre-and postoperative CT scans were obtained using 128-slices CT scanners (Somatom Definition Flash®, Siemens Healthcare, Germany) with 1 mm slice thickness and in-plane resolution of 0.98 mm. The preoperative CT images at 5 mm and 10 mm heights above the lesser trochanter were selected (Fig. 1a). The midcortical-line was defined as the anterior and posterior cortex's angular bisector [13, 18]. The AM-CT is the angle between the midcortical-line and Posterior Condylar Axis (PCA) on each level as proposed [13] (Fig. 1b). The PSA was measured as the angle between the femoral stem neck axis on the axial CT images and the PCA from the postoperative CTs (Fig. 1c). The anatomical coordinate system referred to the International Society of Biomechanics (ISB) recommendations [25].

Measurements based on 3D models

The pre- and postoperative CT images were imported into commercial software (Amira 6.7, Thermo Fisher Scientific, Waltham, MA, USA) to reconstruct the 3D surface models [26]. The anteversion using the midcortical-line and T-line were measured based on the 3D models (AM-3D; AT-3D) [19]. The simulated osteotomy plane was determined through the center of the piriformis fossa and the 5 and 10 mm cutting heights proximal to the lesser trochanter (Fig. 2a). AM-3D was defined as the angle between the midcortical-line (the connecting line between the center of the best fitting circles obtained from the medial and inferior margins of the simulated osteotomy plane) and the PCA [19] (Fig. 2b). AT-3D was defined as the angle between the T-line (the line connecting the trochanteric fossa and the inferior margins of the plane) and the PCA [19] (Fig. 2c).

Statistical analysis

All data met the normal distribution, and the measurements were calculated using Excel 2016 (Microsoft Excel, Redmond, WA, United States). The data were analyzed using the mean values ± standard deviation of PSA, AM-CT, AM-3D, and AT-3D. The differences between AM-CT, AM-3D, AT-3D, and PSA were calculated by the mean difference (MD). Interobserver and intraobserver reliability of the measurements was estimated by the intraclass correlation coefficient (ICC). Pearson correlation coefficients (r) were used to evaluate the correlations between AM-CT, AM-3D, AT-3D, and PSA. The student's t-test was used to determine differences between parameters at 5 and 10mm heights. The power analysis indicated that the sample size reached an 80% statistical power using G*Power software 3.1.9 (Franz Faul, Christian-Albrechts-Universität Kiel, Kiel, Germany). The statistical significance level (α) was set at 0.05.

Results

The ICC for intra-observer and interobserver reliabilities were > 0.9 for all measurements. The two-tailed Pearson correlation coefficients are statistically significant for all measures.

A strong correlation was found for the AM-CT and the PSA at the 5 and 10 mm heights (respectively, r = 0.86 with p-value = 0.000 and r = 0.92 with p-value = 0.000), and no statistically significant difference was found (p-value = 0.662 and 0.495). The mean difference (MD) between the AM-CT at 5 mm height (31.8^{o} ± 15.3^{o}) and the PSA (29.8^{o} ± 17.7^{o}) was 1.9^{o} ± 8.8^{o}, and the MD between the AM-CT at 10 mm height (26.8^{o} ± 14.9^{o}) and PSA was − 3.0^{o} ± 7.1^{o} *(*Table 2*)*.

Table 2
The different anteversions simulated based on various reference landmarks

Parameters	Height (mm)	Angle(°)#	Difference(°)#	t-test p-value	r	Pearson correlation p-value
AM-CT	5	31.8 ± 15.3	1.9 ± 8.8	0.662	0.86	0.000**
	10	26.8 ± 14.9	-3.0 ± 7.1	0.495	0.92	0.000**
AM-3D	5	18.3 ± 12.5	-8.0 ± 11.4	0.046*	0.72	0.000**
	10	16.9 ± 12.3	-9.3 ± 13.2	0.020*	0.61	0.001**
AT-3D	5	45.2 ± 17.5	19.0 ± 15.4	< 0.01*	0.59	0.001**
	10	37.6 ± 15.2	11.3 ± 14.4	0.010*	0.59	0.001**
PSA	N/A	29.8 ± 17.7	N/A	N/A	N/A	N/A

#Expressed as mean ± standard deviation

Difference = (AM-CT/ AM-3D/ AT-3D)-PSA; t-test = student's t-test; r = correlation coefficient;

*Indicates the difference is statistically significant in student's t-test (p-value < 0.05);

**Indicates the Pearson correlation coefficient is statistically significant (p-value < 0.01);

A moderate correlation was found between the AM-3D and the PSA at the 5 and 10 mm cutting heights respectively, r = 0.72 (p-value = 0.000) and r = 0.61 (p-value = 0.001). The mean AM-3D was 18.3° ± 12.5° at 5 mm and was 16.9° ± 12.3° at 10 mm cutting height, which both were significantly smaller than the PSA (p-value = 0.046 and 0.020) *(*Table 2*)*.

A moderate correlation was also found between the AT-3D and the PSA at 5 and at 10 mm cutting heights, respectively, which were both r = 0.59. The mean AT-3D was 45.2° ± 17.5° and was significantly greater than the PSA (p-value < 0.010) at 5 mm cutting height. The mean AT-3D was 37.6° ± 15.2° and was significantly greater than the PSA (p-value = 0.010) at 10 mm cutting height *(*Table 2*)*.

Discussion

The variability in stem version can clinically cause a reduction in ROM. Therefore, different anatomic landmarks have been proposed to predict the PSA [10, 18, 19, 21]. In this study, we compared the prediction accuracy of different landmarks and methods. In particular, we first evaluated and compared the reliability of the midcortical-line and the T-line in predicting PSA for DDH patients. The main finding of this study was that midcortical-line had higher accuracy in predicting the PSA compared to the T-line. Second, AM-CT at 10mm height could be a better choice for clinical prediction of PSA than AM-3D or AT-3D in DDH patients. Because the AM-CT on the axial CT images at the 10 mm height had the strongest correlation (r = 0.92) and minimal difference with PSA (-3.0 ± 7.1°) than other prediction methods. Therefore, clinical use of AM-CT to predict PSA [8, 12, 15], to determine the anteversion of the femoral stem and acetabular cup, can better control the combined anteversion in the safe zone.

The T-line and midcortical-line had different effectiveness in predicting PSA for DDH patients. We found that the prediction of anteversion using the T-line can be significantly greater than the PSA (MD reached 19.0° and 11.3° in the 5 and 10 mm groups). This difference may be explained by the conception of T-line. The T-line is adjusted to get a larger anteversion compared with the midcortical-line. The adjustment corrected the proximal femoral deformity of DDH patients due to the disease. Therefore, T-line can be a useful intraoperative reference that helps reproduce the NFA as the high correlation with the NFA reported in the article of Tsukeoka et al. [21]. However, the orientation of the cementless femoral stem in implanting was mainly dependent on the geometric shape of proximal medullary cavity. The intraoperative twist and press-fit result in a certain pathological anteversion but lead to the deviation from the anteversion of the T-line landmark.

On the other hand, the midcortical-line strongly correlated with PSA of DDH patients, which is consistent with the previous studies [13, 18]. This phenomenon can be explained that the midcortical-line between the anterior and posterior cortical line met an actual axis of femoral anteversion [18], which may influence the orientation of cementless stem in THA during implanting. Moreover, the samples selected in this study included Crowe I-IV DDH patients with the posterolateral approach, which expands the application range of the conclusion that the AM-CT could be a reliable landmark for predicting the PSA of DDH patients.

The height of the anatomic landmark is critical to the accuracy of prediction. According to the previous studies [13, 18, 21], 5 and 10 mm heights proximal to the base of the lesser trochanter are commonly chosen for osteotomy, which can preserve bone mass and prevent trochanteric fractures. In this study, we observed a strong correlation between the AM-CT at the two levels (5 and 10mm height proximal to the lesser trochanter) and the PSA. We found the AM-CT at 10 mm height was better than that at 5 mm for predicting the PSA for Crowe I-IV patients. These results may be because morphological characteristics of the distal femoral medullary cavity in DDH femurs tend to be more circinal or elliptical [10, 30], which creates more difficulties in confirming the anterior and posterior cortex. Therefore, 5 mm height proximal to the base of the lesser trochanter of the CT slices may cause a slight deviation in confirming the midcortical-line compared to the 10 mm height group. Moreover, the circinal or elliptical medullary cavity in the distal location can provide a relatively greater adjustive range for stem implantation, which resulted in the difference between PSA and predicted stem anteversion [27]. Therefore, the CT images at 10 mm above the proximal end of the lesser trochanter are advised to use in preoperative planning for DDH patients accurately.

To the best of our knowledge, the present study was the first to investigate the accuracy of midcortical-line landmarks in predicting the PSA of DDH patients. Our results confirmed the AM-CT was better than the AM-3D in predicting PSA of DDH patients as the AM-CT had a higher correlation with PSA. Moreover, the AM-CT did not show a significant difference with PSA while AM-3D had a significant difference with PSA in the 10 mm group. The explanation of this phenomenon is that the design of cementless femoral stems is mainly based on the medullary cavity morphology according to CT images [28]. Therefore, the postoperative anteversion of cementless stems with adaptation in implanting may be relatively consistent with the positional relationship between the stem and the proximal femoral medullary canal observed on CT images. This may also explain why the midcortical-line from cross-sectional CT planes can be better correlated with PSA than the 3D models. Therefore, the AM-CT based on the axis CT images was more appropriate for predicting the PSA than the AM-3D based on the 3D models in the preoperative planning. Furthermore, although using the 3D models can simulate the THA surgical procedure, we did not find other landmarks from the osteotomy planes of the 3D femoral model that have high effectiveness in predicting PSA in this study. Therefore, we believe preoperative planning based on CT images provides a good solution for predicting the PSA.

Inevitably, this study has several limitations. First, the sample size of this study was small. However, the power analysis indicated that the sample size reached 80% statistical power. The Pearson correlation coefficient is statistically significant at the 0.05 level (two-tailed), which verified the validity of the sample. The sample size of this experiment has certain reliability. Second, even though the cementless stem was reported as one of the most extensively used stems in younger patients, the use of only one type of femoral stem in this study was limited to a certain extent [29, 30]. The cementless stem design mainly relies on the profile of the femoral medullary cavity based on the CT cross-section [31, 32]. Other femoral stem types may affect the femoral anteversion after implantation.

Conclusion

The main finding of this study was that the AM-CT was the most reliable preoperative reference guide for predicting the PSA when compared to the AM-CT and the AT-3D in DDH patients. AM-CT at 10 mm height was better than 5 mm height proximal to the base of the lesser trochanter in DDH patients. The necessity of preoperative planning is also demonstrated in this study, as it may be challenging to find reliable intraoperative landmarks which can accurately predict the PSA for DDH patients. This conclusion could generally apply to DDH patients.

Abbreviations

DDH
Developmental Dysplasia of the Hip
CT
Computed Tomography
THA
Total Hip Arthroplasty
ICC
Interclass Correlation Coefficient

AM-CT
The Anteversion Using the Midcortical-line based on CT
AM-3D
The Anteversion Using the Midcortical-line based on 3D models
AT-3D
The Anteversion Using the T-line based on 3D models
PSA
Postoperative stem anteversion
LCEA
lateral Center-edge Angle
ISB
International Society of Biomechanics
ROM
Range of Motion
IMI
The Intersection of Midcortical-line with the Inferior Margins of the Plane

Declarations

Ethics approval and consent to participate: The informed consent was signed by all subjects. Approval was granted by the Scientific Research Projects Approval Determination of Independent Ethics Committee of Shanghai Ninth People's Hospital affiliated to Shanghai Jiao Tong University, School of Medicine (No.SH9H-2019-T109-1). This study was performed in line with the principles of the Declaration of Helsinki.

Availability of data and materials: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request. All data and materials as well as software application or custom code support their published claims and comply with field standards.

Competing interests: The authors declare that they have no competing interests. No conflict of interest should be declared. The authors have no relevant financial or non-financial interests to disclose and no conflict of interest should be declared. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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Author Contributions All authors contributed to the study's conception and design. Material preparation and analysis were performed by [Ziang Jiang], [Rongshan Cheng], and [Chunjie Xia, Junjie Liang], data collection was performed by [Liao Wang], and article modification was performed by [Tsung-Yuan Tsai] and [Willem Alex Kernkamp]. The first draft of the manuscript was written by [Ziang Jiang] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

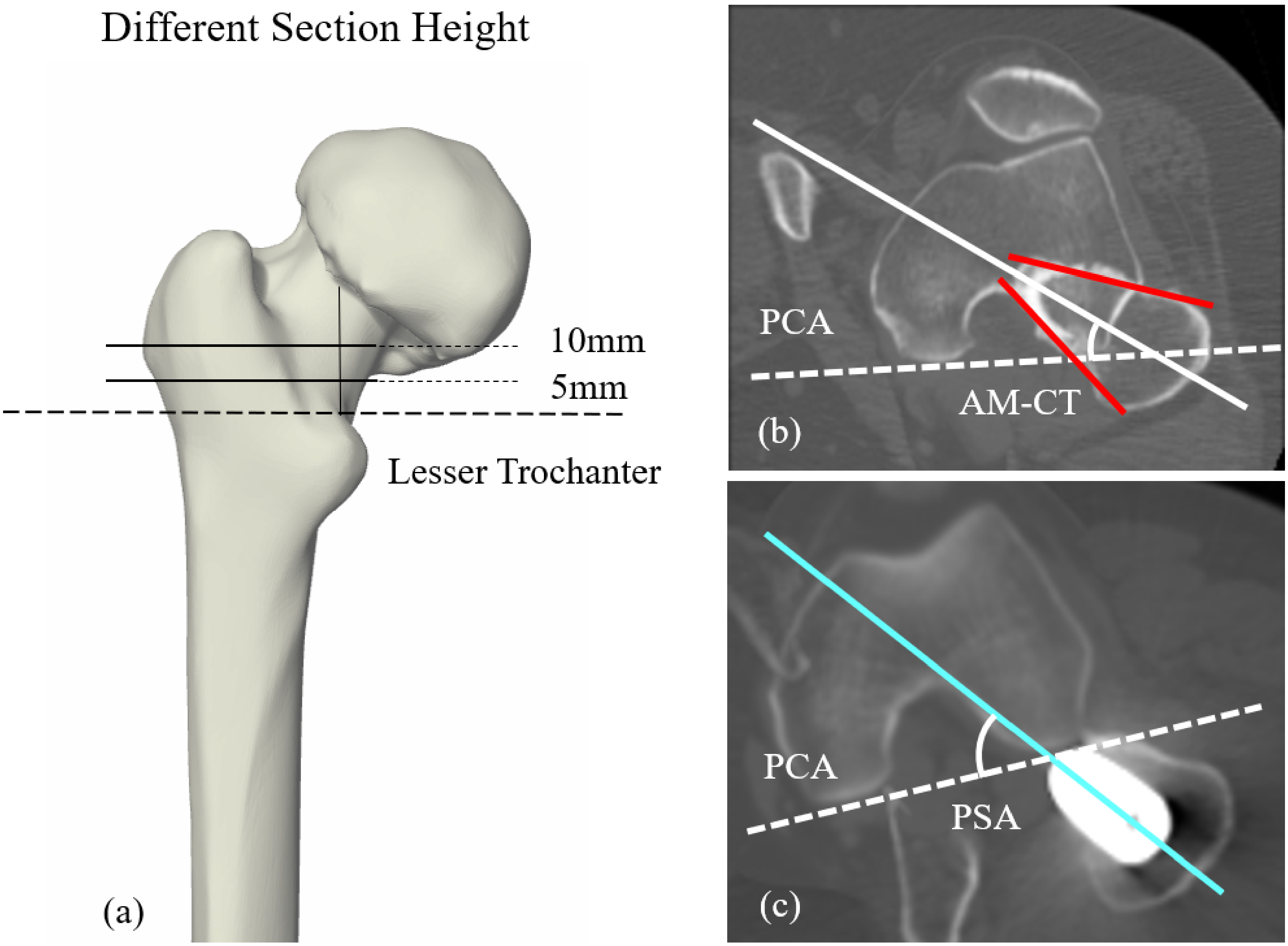

Figure 1

The schematic illustration of the measurements based on CT.

(a) The selection of two different CT section height on femur, which are 5 mm and 10 mm height above the proximal end of the lesser trochanter. (b) AM-CT was defined as the angle between the PCA (white dotted line) and the midcortical-line (white solid line), which is the angular bisector of anterior cortex and posterior cortex (red solid line). (c) PSA was defined as the angle between the PCA and the femoral stem neck axis (bright sky blue solid line).

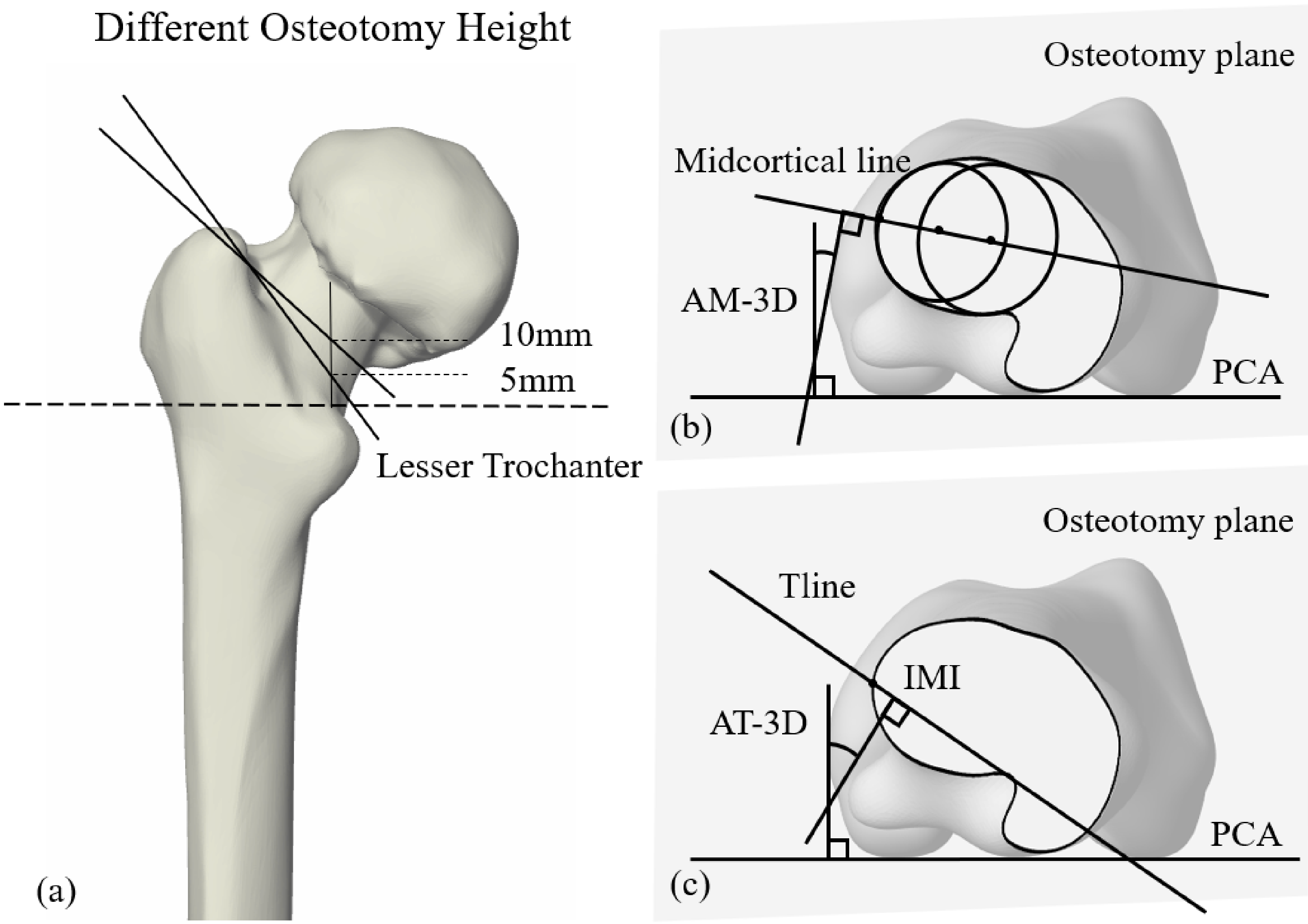

Figure 2

The schematic illustration of the measurements based on 3D model.

(a) The simulated osteotomy plane pass through the center of piriformis fossa and the location at the 5mm and 10mm heights above the lesser trochanter. (b) AM-3D was defined as the angle between the midcortical-line and the PCA. (c) AT-3D was defined as the angle between the PCA and the T-line. IMI was the intersection of midcortical-line with the inferior margins of the osteotomy plane.