Reliability and validity of the functional combined anteversion measurement method using standing lateral radiography after total hip arthroplasty

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Background: The functional safe zone of combined anteversion (CA) shows a superior predictive value for dislocation after total hip arthroplasty (THA) compared to that of the Lewinnek safe zone. Thus, it is necessary to establish a feasible and accurate method for assessing CA for the evaluation of dislocation risk. We aimed to evaluate the reliability and validity of using standing lateral (SL) radiographs for determining CA.

Methods: Sixty-seven patients who underwent SL radiography and computed tomography (CT) scans after THA were included. Radiographic CA values were obtained via the calculation of the sum of the acetabular cup and femoral stem anteversion (FSA) measurements as obtained from the SL radiographs. Acetabular cup anteversion (AA) was measured based on the tangential line to the face of the cup, whereas FSA was calculated using the developed formula based on the neck-shaft angle. The intra-observer and inter-observer reliabilities for each measurement were examined. Radiological CA values were compared with the CT scan measurements to evaluate their validity.

Results: The intra-observer and inter-observer agreements of the SL radiography were excellent [intraclass correlation coefficient (ICC) ≥0.90]. The radiographic measurements correlated well with the CT scan measurements (r=0.869, P<0.001). The mean difference between the radiographic and CT scan measurements was −0.55°±4.68° and ranged from 0.3° to 2.2° in terms of the 95% confidence interval (CI).

Conclusions: SL radiography is a reliable and valid imaging tool for the assessment of functional CA.

Keywords: Total hip arthroplasty; dislocation; combined anteversion; standing lateral radiograph

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Introduction

Incorrect positioning of components is one of the major factors responsible for poor prognosis after total hip arthroplasty (THA) and might result in dislocation, impingement, and wear (1-5). A safe zone (40°±10° of inclination and 15°±10° of anteversion) for the acetabular component was established by Lewinnek *et al.* in 1978, and it served as a reproducible guide for preventing adverse outcomes (1). However, recently, numerous studies have questioned the accuracy of the Lewinnek safe zone in predicting hip stability after THA (6-9). A large retrospective cohort study found that the majority of acetabular components are present within the Lewinnek safe zone in dislocated THA (6). Another systematic review showed that most acetabular cups implanted inside the Lewinnek safe zone did not significantly reduce dislocation rates (7).

Pelvic motion due to postural changes has a significant impact on the cup position (10-14). The orientation of the acetabular prosthesis obtained at surgery and measured by standard anteroposterior radiographs or computed tomography (CT) scans of the pelvis in the supine position was not equivalent to that in the functional positions, such as standing or sitting positions (10,14). In particular, the difference between the cup anteversion in the sitting and supine positions was more significant than that between the cup anteversion in the sitting and standing positions (10). This difference has been demonstrated to cause prostheses placed near the extremes of the safe zone to fall outside the safe zone (13). Similarly, Tiberi *et al.* reported that 31% 'well-positioned' cups became 'malpositioned' upon standing (14). Lumbar lordosis causes the pelvis to tilt posteriorly (12,15-17), and the coverage of the femoral head tends to decrease during the transition from the supine to the standing position (17-20). This sagittal spine-pelvis-hip motion determines the dynamic changes in the acetabular cup during body functional movements during THA (8). This may account for the poor predictive value of the Lewinnek safe zone for impingement or dislocation after THA.

The functional position of the hip includes the change in the acetabulum position caused by sagittal pelvic motion as well as the motion of the femur from extension to flexion. A thorough evaluation of the hip joint can only be performed by combining the mobility of the acetabulum and that of the femur (8,21). In THA, the full evaluation of hip component mobility requires accurate measurement of the combined anteversion (CA), which is the sum of the acetabular cup anteversion (AA) and femoral stem anteversion (FA). This is a measurement of the sagittal functional hip component motion and thus an indicator of the functional safe zone (8,9,22). A previous study proved that the acetabular position alone cannot predict hip dislocation, and the femoral implant position is also essential in determining the functional outcomes of THA (23). CA is closely associated with hip dislocations (2,24). To assess sagittal functional CA after THA, it is necessary to measure the AA and FA using standing lateral (SL) radiographs of the pelvis and hip, including the whole femoral stem. To the best of our knowledge, the method used to measure CA on SL radiographs has not yet been reported.

In our previous study, the reliability and accuracy of SL radiograph method for measuring AA was verified (25). Subsequently, we developed a formula based on the neck-shaft angle (NSA) for calculating FA on SL radiographs. The research method for this formula is detailed in the Appendix 1. In the present study, we evaluated the reliability and validity of using SL radiographs for determining CA based on the proposed measuring method of AA and FA. We prepared this article in accordance with the MDAR reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-3243/rc).

Highlight box

Key findings

- Standing lateral radiography is a reliable and valid imaging tool for the assessment of functional combined anteversion.

What is known and what is new?

- The functional safe zone of combined anteversion shows a superior predictive value for dislocation after total hip arthroplasty compared to that of the Lewinnek safe zone. But a reliable method for measuring radiographic functional combined anteversion is lack.
- A reliable and valid radiographic method for measuring functional combined anteversion was developed and verified.

What is the implication, and what should change now?

- The proposed method is reliable and accurate for evaluating functional combined anteversion. It can be further applied to explored the relationship between functional combined anteversion and hip dislocation and thus a functional safe zone can be built as a reproducible guide for the prevention of dislocation after THA implantation.

Methods

Patient selection

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Institutional Ethics Committee of the Sun Yat-sen Memorial Hospital (No. SYS-EC2-SOP-008-01.0-A05) and informed consent was obtained from all the patients. A consecutive series of 156 patients who underwent THA between June 2020 and December 2021 were screened. The inclusion criteria were as follows: those who (I) underwent unilateral primary cementless THA; (II) were over 18 years of age; and (III) underwent SL radiography and CT 1 week after THA. The exclusion criteria were as follows: those who (I) experienced previous pelvic or spinal surgery; (II) experienced pelvic or spinal deformity; (III) underwent simultaneous bilateral THA; and (IV) did not undergo postoperative SL radiographs and CT scans.

All THAs were performed by four experienced orthopedic surgeons, with the patient in the lateral decubitus position, using a posterolateral approach. The same press-fit acetabular components (R3 Acetabular System, Smith & Nephew, Inc., Memphis, TN, USA) and cementless stems with an NSA of 135° (POLARSTEM, Smith & Nephew, Inc.) were used in all patients. Tribological pairing consisted of a neutral polyethylene liner and a ceramic head with a diameter of 32 or 36 mm.

Imaging techniques

SL radiography and CT scans were arranged when patients could stand steadily after surgery. All SL radiographs and CT scans were obtained using the following acquisition protocols suggested by the same group of radiology technicians.

During SL radiography, the patients were instructed to stand straight with the involved hip and knee extended, and the contralateral leg stepped backward to avoid occlusion of the femoral condyle on the contralateral side with that on the operated side (*Figure 1A*). To ensure that the femur was neutral, the tube was moved center to the femoral condyle and then the patients were instructed to rotate their involved legs until the lateral femoral and medial femoral condyles were aligned under X-ray fluoroscopy (*Figure 1B*). Afterwards, the tube was moved upwards and centered on the proximal femur. Finally, SL radiographs of the region extending from the sacral promontory to the lowermost margin of the femoral stem were obtained under standardized conditions (focus-film distance 115 cm, 75 kV, automatic exposure).

During CT scanning, the patients were positioned supine with the bilateral hip joints in a neutral position. The collimation was set at 0.63 mm, the field of view at acquisition was 30 cm, and the slice thickness was 0.67 mm with 0.33 mm increments (50% section overlap).

CA measurements

CA was calculated by the addition of AA and FA. In the SL radiograph, AA was defined as the angle between a tangential line drawn to the opening face of the acetabular cup and the horizontal plane. The tangential line of the open face of the cup was drawn by connecting the two points formed by the intersection of a circle drawn around the acetabular cup and the ellipse formed by the open face of the cup. FA was calculated using the following formula:

$$\mathrm{FA} = -4.58 \times \mathrm{NSA} + 0.01 \times \mathrm{NSA}^2 + 469 \quad [1]$$

FA, femoral stem anteversion; NSA, neck-shaft angle.

NSA was defined as the angle between the axis of the neck and the axis of the femoral stem (*Figure 2A*). CA was calculated by the addition of AA and FA values obtained from the SL radiograph and was defined as radiographic CA.

For the CT imaging, the angle formed between the line through the most anterior and posterior points of the cup's open face and the line perpendicular to the functional coronal plane was defined as AA (26,27). Pelvic tilt (PT) was defined as the angle between the horizontal plane and a line connecting the upper border of the symphysis with the sacral promontory according to a previous report (28) (*Figure 2B*). Before AA measurement, the PT on CT images was set to that on the SL radiograph to minimize the error due to PT variation with postural change. FA was defined as the angle between the axis of the femoral stem and the posterior intercondylar line (*Figure 2C*) (29,30). CA was calculated by the addition of AA and FA values obtained from the CT image and was defined as CT-CA.

Assessment of reliability and accuracy

Reliability was defined as the consistency in measurements. Intra-observer reliability for each method was assessed using measurements obtained by an examiner who performed the reassessment 4 weeks later. Inter-observer reliability for each method was assessed using measurements obtained

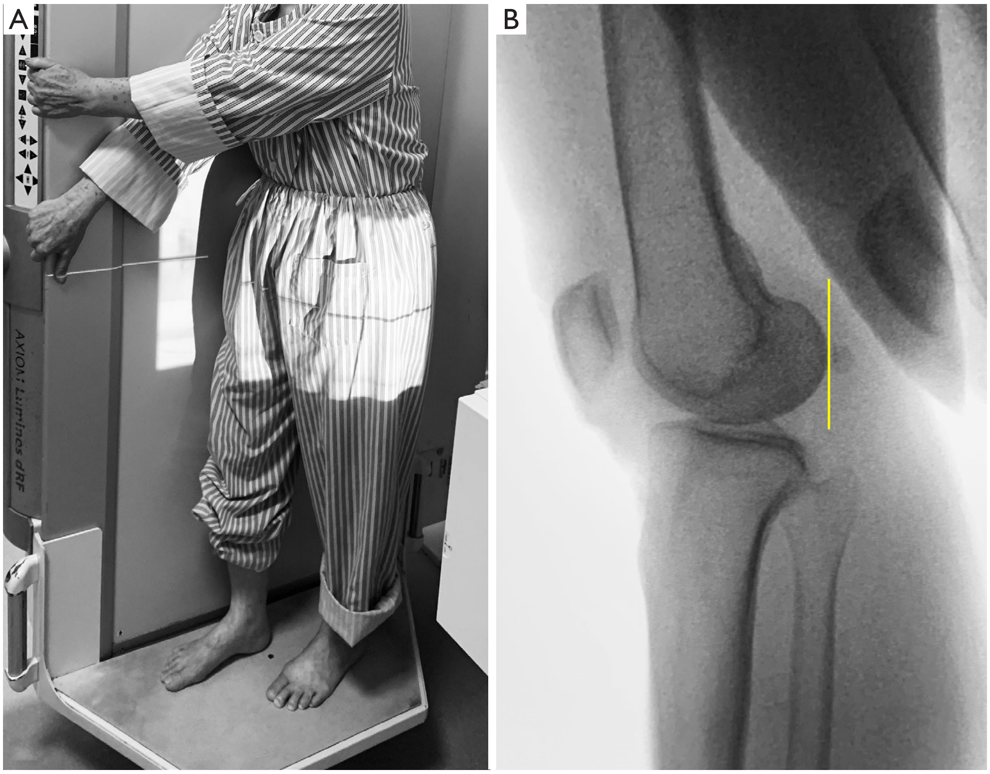

Figure 1 Standing lateral radiograph. (A) The patient was instructed to stand straight with the involved hip and knee extended, and the contralateral leg stepped backward. (B) The rotation of the femur was eliminated by aligning the lateral femoral condyle with the medial femoral condyle under X-ray fluoroscopy. The yellow line represents that the lateral femoral condyle and the medial femoral condyle is aligned for eliminating rotation of the femur. This image is published with the patient/participant's consent.

by the same two examiners. Accuracy was defined as the proximity of the research method to the reference standard for CT scans.

Statistical analyses

Precision analysis was performed using intraclass correlation coefficients (ICCs) at a target value of 0.8 and a 95% confidence interval (CI) of 0.2. The minimum sample size was estimated to be 34 hip surgeries (31). ICC (32) is one of the reliability coefficient indices used to measure the test-retest reliability and CI shows the degree to which the true value of a parameter has a certain probability to fall around the measurement result.

The intra-observer and inter-observer reliabilities of all measurements were calculated using ICC and 95% CI. A two-way, random-effects intraclass correlation model and absolute agreement were used to calculate the ICC. A coefficient major greater than 0.7 was considered adequate for reliability (33).

The radiographic and CT measurements were compared using paired *t*-tests to assess accuracy. Correlations between radiological CA and CT-CA were analyzed. Pearson's correlation coefficient (r) was used to evaluate the consistency between the radiographic anteversion and referenced CT anteversion. Correlations were evaluated as poor (0.00 to 0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), good (0.61 to 0.80), or excellent (0.81 to 1.00) (34). A Bland-Altman plot was constructed to demonstrate the differences. The differences within the 95% limits of agreement (95% LoA) were clinically acceptable and means a good agreement between the two methods. Statistical analyses were conducted using SPSS for Windows (version 25.0; SPSS Inc., Chicago, IL, USA), and statistical significance was set at $P<0.05$.

Results

Demographic data

This study included 67 patients, of which 31 were male

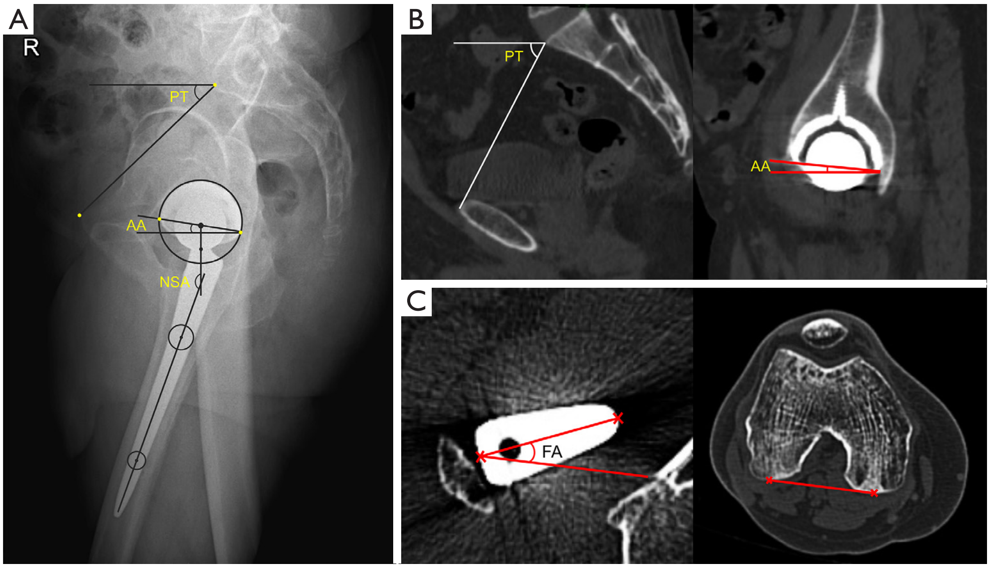

Figure 2 The measuring methods of the parameters. (A) Standing lateral radiographic measurements. AA is the angle between the horizontal plane and a tangential line drawn to the open face of the cup. FA is calculated using the Eq. [1]. NSA is the angle between the axis of the neck and that of the stem. PT is the angle between the horizontal plane and a line connecting the upper border of the symphysis with the sacral promontory. (B,C) CT measurements. (B) AA is measured between the line passing through the most anterior and posterior points of the cup's open face and the line perpendicular to the functional coronal plane after standardizing the PT with a radiograph. (C) FA is the angle between the axis of the stem and the posterior intercondylar line. AA, acetabular cup anteversion; FA, femoral stent anteversion; NSA, neck-shaft angle; PT, pelvic tilt; CT, computed tomography.

Table 1 The demographics of the patients (n=67)

Parameters	Value
Age (years), mean ± SD	56.42±14.65
Gender (male/female), n	31/36
BMI (kg/m^2), mean ± SD	23.48±4.28
Operated side (left/right), n	31/36
Preoperative diagnosis, n (%)	
Osteoarthritis	29 (43.3)
Femoral head osteonecrosis	26 (38.8)
Femoral neck fracture	12 (17.9)
Type of prosthesis, n (%)	
R3 Acetabular cup (Smith & Nephew)	67 (100.0)
POLARSTEM cementless stem (Smith & Nephew)	67 (100.0)

BMI, body mass index; SD, standard deviation.

and 36 were female, with a mean age of 56.42±14.65 years and a mean body mass index of 23.48±4.28 kg/m^2. The primary diagnoses were osteoarthritis in 29 hips (43.3%), femoral head osteonecrosis in 26 (38.8%), and femoral neck fracture in 12 (17.9%). The patient demographics are shown in *Table 1*.

Accuracy of discrimination between anteversion and retroversion

Three acetabular cups with a backward version angle opening (*Figure 3A*) and five femoral stems (*Figure 3B*) with a backward NSA opening on the SL radiograph were retroverted. The true direction of these retroverted acetabular cups (*Figure 3C*) and femoral stems (*Figure 3D*) was determined using the corresponding CT images. The measured value for the retroverted prosthesis was defined as negative.

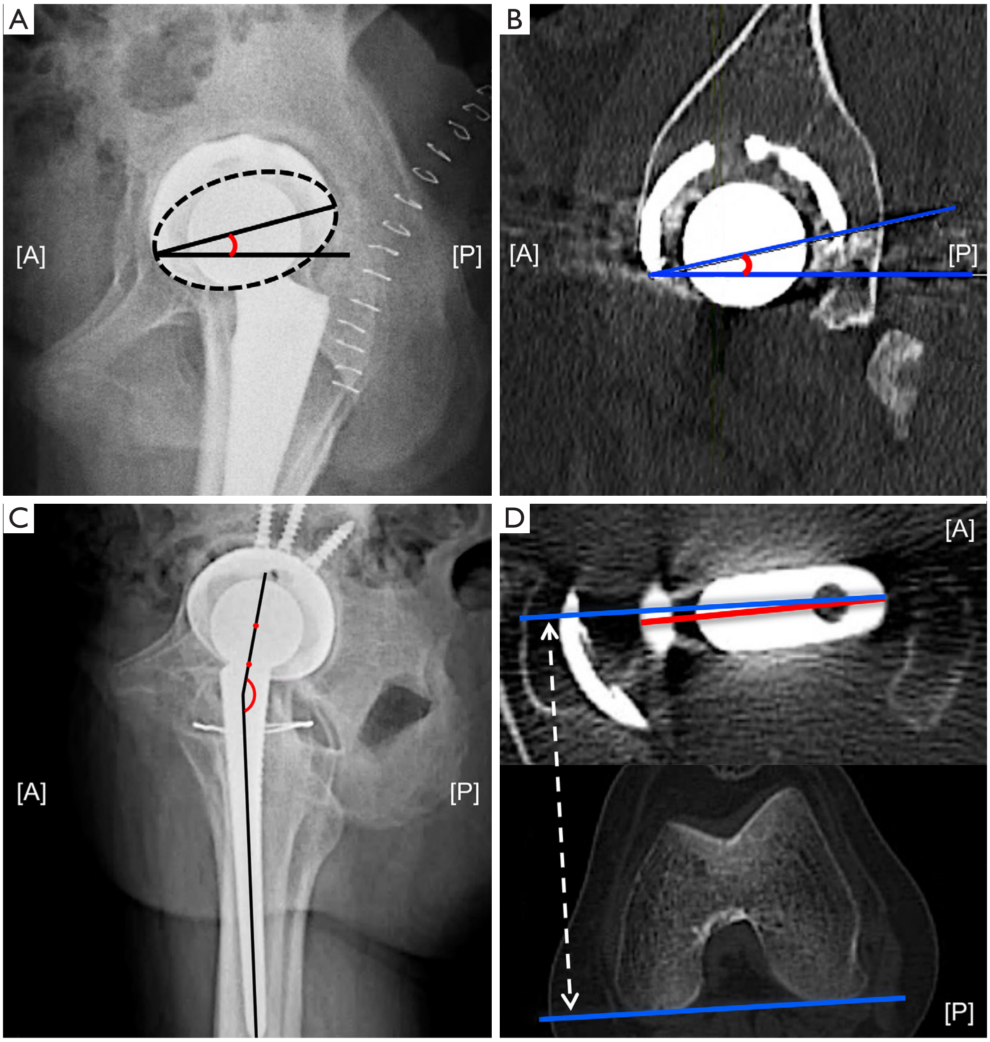

Figure 3 An example showing the identification of the retroverted component on a standing lateral radiograph. The opening of the AA (A) and the NSA (C) orienting posteriorly represents the acetabular cup and the femoral stem retroverted, respectively, which is verified on corresponding CT images (B,D). A, anterior; P, posterior; AA, acetabular cup anteversion; NSA, neck-shaft angle; CT, computed tomography.

Reliability and accuracy of the method

The intra-observer and inter-observer reliabilities were satisfactory for the CA values obtained from SL radiographs (r=0.963 and 0.915, respectively; P<0.001) and CT scans (r=0.984 and 0.986, respectively; P<0.001) (*Table 2*). The mean radiographic CA and CT-CA were 28.96°±9.00° and 29.51°±9.79°, respectively. The correlation coefficient for the correlation between radiographic and CT measurements was 0.869 (P<0.001) (*Figure 4*). The individual differences between radiographic CA and CT-CA are shown in the Bland-Altman plots (*Figure 5*). The mean difference was −0.55°±4.68° and was expected to range between 0.3° and 2.2° according to the 95% CI.

Discussion

CA is calculated as the sum of AA and FA in THA. The anteversion or retroversion of implants determines whether the version measurement is positive or negative, which has a significant impact on the CA measurement value. Therefore, the differentiation between anteversion and retroversion of the hip prosthesis is essential for measuring

Table 2 Intra- and inter-observer reliability of each measuring method

Measuring methods	Intra-observer reliability		Inter-observer reliability	
	ICC	95% CI	ICC	95% CI
Radiograph	0.963	0.940 to 0.977	0.915	0.861 to 0.948
CT scan	0.984	0.973 to 0.990	0.986	0.977 to 0.991

ICC, intraclass correlation coefficient; CI, confidence interval; CT, computed tomography.

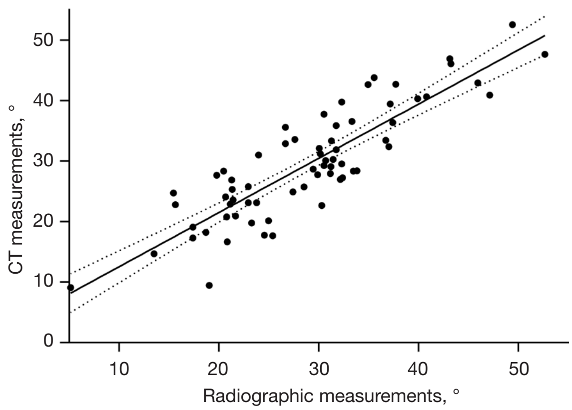

Figure 4 Scatter plot of radiographic CA and CT-CA with the correlation slope. CA, combined anteversion; CT-CA, computed tomography-combined anteversion.

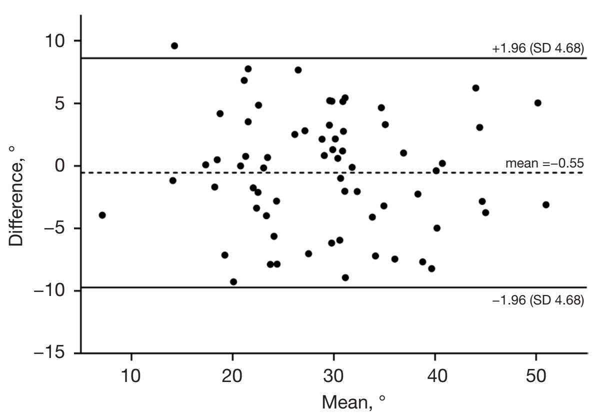

Figure 5 Bland-Altman plot showing the difference between radiographic CA and CT-CA. The dashed line represents the mean difference in the measurements, and the straight lines represent the 95% limits of agreement (mean ± 1.96 SD). CA, combined anteversion; CT-CA, computed tomography-combined anteversion; SD, standard deviation.

CA. The previous methods used for measuring the component version using anteroposterior (AP) radiographs make it difficult to differentiate between anteversion and retroversion (35,36); therefore, they are not applicable for evaluating CA. Our study confirmed the validity of using SL radiographs in distinguishing between anteversion and retroversion of the components. When the openings of the AA and NSA were directed posteriorly, it indicated that the component was anteverted and retroverted, respectively, which was verified by corresponding CT imaging.

A few reports on radiographic methods used for measuring functional CA in the standing position have been published. Recently, researchers have used a standing radiological method with low-dose biplanar radiography (EOS) to evaluate functional CA. Morvan *et al.* used the EOS system to evaluate the component version in THA performed using an anterior surgical approach; however, they did not introduce the specific measurement methods and did not evaluate the consistency between radiographic CA and CT-CA (37). Esposito *et al.* reported that the mean differences in CA measurements obtained from EOS compared with those obtained from CT were 3°±2° for AA and 4°±4° for FA, which were larger than those obtained in our study (38). The Pearson correlation coefficient was greater than 0.78, which was similar to that in our study. However, the data on CA measurement error were not presented, and the specific approach used for AA and FA measurement was not mentioned in the study conducted by Esposito *et al.* Although EOS enables component version assessment in the standing position with low radiation dose, this technology is still not economical and universal, and its corresponding measurement methods have not been well-verified.

Except for the EOS system, the previous methods used to evaluate CA involved measuring AA and FA using pelvic AP (22,29) or lateral radiographs (39,40), respectively. As previously explained, the AP radiographic method is inapplicable for evaluating CA due to its inability to distinguish between retroversion and anteversion of the hip prosthesis. The lateral radiographic methods for assessing CA involved measuring AA and FA on cross-table lateral radiographs (39) and Budin-modified lateral radiographs (40), respectively, which meant double of the radiation exposure and increased cost. In contrast, our method involves evaluating the CA using a single lateral radiograph; therefore, it is more advantageous. Regarding measurement accuracy, the previous studies reported that the mean difference between these methods and CT scans was −4.6° to 3.9° for AA (22) and −2.2° to 4.5° for FA (41), which were higher than those obtained in our results. This difference may partly have resulted from PT variations caused by the special imaging body position (42). Moreover, these methods were unable to assess functional CA in the standing position and are unsuitable for patients with joint stiffness and obesity (41).

This study had some limitations. Firstly, our method is not applicable to patients undergoing bilateral hip replacement. Since the bilateral hip prostheses overlap on the lateral radiograph, some essential measurement markers may be occluded and auxiliary lines cannot be established, making the measurement procedure improbable. Secondly, the projection of the acetabular cup with an excessive inclination angle on the lateral radiograph is close to an equal circle; therefore, the determination of the tangent line drawn to the acetabular cup opening and the differentiation between anteversion and retroversion may be difficult. Finally, for femoral stems with a small tilt angle (−3° to 3°), it is difficult to determine whether they tilt anteriorly or posteriorly on SL radiographs because the NSA is close to 180°.

Conclusions

In general, the proposed method, which uses SL radiography for evaluating functional CA, is reliable and accurate and is equipped with the advantage of simultaneously assessing sagittal pelvic rotation; thus, it can be applied in the sitting or supine positions. Further multicenter studies with large sample sizes and long follow-up durations should be conducted to explore the relationship between functional CA and hip dislocation under different postural changes using the proposed method for a functional safe zone to be built as a reproducible guide for the prevention of dislocation after THA implantation.

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Footnote

Reporting Checklist: The authors have completed the MDAR reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-3243/rc

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-3243/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-3243/coif). All authors report that this study was funded by the National Key R&D Program of China (No. 2021YFA1102600), National Natural Science Foundation of China (No. 82002293), Science and Technology Planning Project of Guangzhou City, China (No. 201803010011); Guangdong Basic and Applied Basic Research Foundation (Nos. 2019A1515011647, 2021A1515010693, 2021A1515010294, 2022A1515010256). The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Ethics Committee of the Sun Yat-sen Memorial Hospital (No. SYS-EC2-SOP-008-01.0-A05) and informed consent was obtained from all the patients.

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Supplementary

Appendix 1

Preliminary study of the stem anteversion measurement method

A preliminary study was conducted to reveal the relationship between the true stem anteversion from CT images and the projected neck–shaft angle (p-NSA) from the simulated true lateral view using digitally reconstructed radiographs (DRRs). DRRs were generated from CT data using ray casting to produce an image similar to that of a clinical radiograph. We used DRR technique to generate simulated standard standing lateral radiographs of 50 subjects based on CT data, in which the involved femurs of the CT model were adjusted to a neutral position. The p-NSA of femoral stem was measured on the DRR image, which was defined as the angle between the stem-neck axis (*Figure S1A*) and the axis of stem (*Figure S1B*). The true stem anteversion was measured between the posterior intercondylar line (*Figure S2A*) and the axis of the stem (*Figure S2B*) on the CT reconstructed image.

The measurement results of the p-NSAs and the true stem anteversions for each patient were seen in the *Table S1*. Curve fitting analysis was used to explain the relationship between p-NSAs and true stem anteversions. An Eq. [1] was established (R=0.765, P<0.001). We further statistically validated the equation using the models of residual, normal Q-Q, scale location, and residuals *vs.* leverage. The results showed that the equation met statistical test assumptions.

$$\alpha = -4.58 \times \beta + 0.01 \times \beta^2 + 469 \quad [1]$$

α: radiographic stem anteversion, β: projected-neck-shaft angle

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Table S1 The p-NSAs and the corresponding true stem anteversions for each patient

Patients ID	NSA* (°)	True-FA (°)
1	153.0	22.3
2	151.4	32.2
3	157.9	29.7
4	151.1	26.1
5	170.4	8.9
6	164.6	7.4
7	151.9	22.8
8	165.6	10.0
9	171.2	4.2
10	153.0	25.7
11	157.1	27.5
12	157.1	22.9
13	171.4	10.8
14	161.8	16.9
15	164.5	15.3
16	169.9	12.3
17	167.1	12.6
18	179.4	2.1
19	173.3	5.3
20	162.9	7.9
21	172.3	6.9
22	157.8	25.8
23	162.5	17.0
24	157.3	14.9
25	164.7	15.9
26	154.1	24.6
27	159.6	22.4
28	156.7	16.9
29	159.4	11.4
30	158.2	14.1
31	178.3	1.2
32	174.7	4.2
33	161.0	14.3
34	157.1	18.9

Table S1 (*continued*)

Table S1 (*continued*)

Patients ID	NSA* (°)	True-FA (°)
35	168.5	6.3
36	172.5	6.2
37	163.1	14.1
38	163.4	13.8
39	161.1	7.3
40	174.0	5.1
41	157.0	26.7
42	172.5	5.5
43	162.1	15.8
44	154.0	25.8
45	159.6	20.4
46	162.2	23.9
47	156.4	23.2
48	148.6	21.5

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Figure S1 The p-NSA of femoral stem on the DRR image was defined as the angle between the stem-neck axis (A) and the axis of stem (B). p-NSA, projected neck-shaft angle; DRR, digitally reconstructed radiograph.

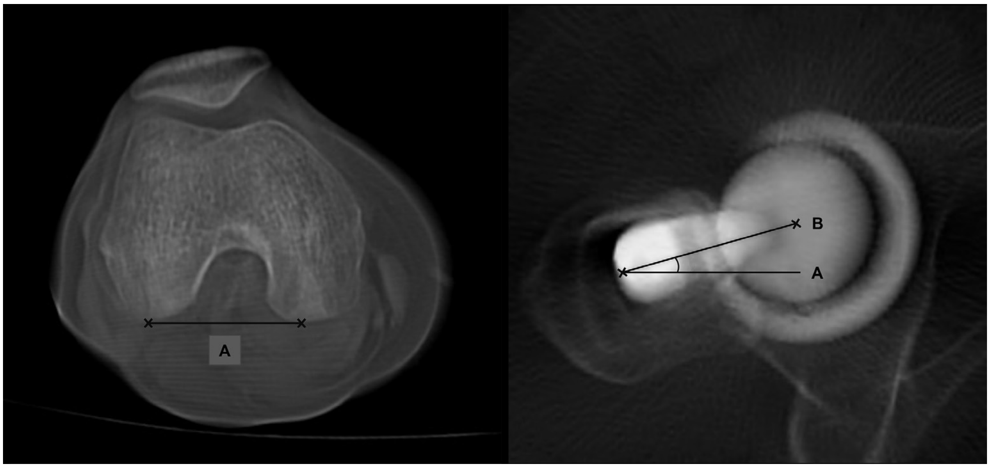

Figure S2 The true stem anteversion was measured between the posterior intercondylar line (A) and the axis of the stem (B) on the CT reconstructed image.

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