A Study on the Reliability and Validity of the Standing Lateral Radiograph Method to Assess Acetabular Component Version

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Abstract

Objectives: Version of the acetabular component on standing position is an important factor influencing the risk of adverse outcomes during functional activities after total hip arthroplasty (THA). The main objective of this study was to evaluate the reliability and validity of a method for measuring cup version on standing lateral (SL) radiograph.

Methods: 87 consecutive patients who underwent primary THA were included. SL radiograph and computed tomography (CT) scan were taken 7 days after THA to measure the cup version. The measurement method was based on the cross-table lateral (CL) radiograph. The tangential line of the cup opening face was determined through two intersecting points of the cup outer edge circle and the opening face elliptical arc. The version was measured between the horizontal line and the tangent line by two independent examiners. Radiographic measurements were compared with CT measurements after the uniformization of pelvic tilt (PT).

Results: All measurements had excellent intra- and inter-observer reliabilities with an intraclass correlation coefficient (ICC) >0.90 . The mean version was 15.56° (SD 11.22° , -19.82° to 38.74°) for SL radiographs and 16.19° (SD 12.09° , -23.00° to 47.20°) for PT-matched CT. There was a positive correlation ($r = 0.901$, $p < 0.001$) between radiographic versions and CT versions. The mean difference was -0.63° (SD 5.25° , -14.92° to 12.72°) and the differences were almost within the 95% limits of agreement.

Conclusion: SL radiograph allows accurate and practicable evaluation of post-operative functional acetabular cup version, with an advantage to identify the pelvic tilt simultaneously.

Introduction

Malposition of the acetabular prosthesis after total hip arthroplasty (THA) has been associated with dislocation, component loosening, polyethylene wear, and adverse clinical outcomes, including pain and diminished joint mobility [1-4]. Accurate measurement of the acetabular component position is vital for the assessment of outcomes after THA. The orientation of the acetabular component can be resolved into two angles: inclination angle and version angle [5]. While computed tomography (CT) scans are known to provide an accurate evaluation of the component position, plain radiographs continue to be commonly used owing to the high cost and considerable radiation involved with CT scans [6-8]. The anteroposterior (AP) pelvic radiograph is the standard method for inclination angle measurement [9], whereas the optimal plain radiographic method for cup version measurement is currently not favored in consensus. AP radiographs and cross-table lateral (CL) radiographs are two known radiographic methods used to assess component anteversion. However, existing literature has conflicting reports on the accuracy of the two methods [10-15].

Pelvic tilt (PT) has been reported to make the component version inaccurate [16-19]. One degree of PT changed anteversion by an average of 0.8° on the coronal plane [17]. A previous study found a similar effect of PT on cup version measurement on CL radiographs [20]. Moreover, the acetabular component

version may change into or out of the conventionally defined “safe zone” from the supine to the standing position [19]. Accordingly, the cup position assessed on supine CL radiograph seems not applicable to estimate the postoperative functional position of standing. Besides, the PT-relevant landmarks on CL radiograph are not clear, making a supplementary lateral film essential to measure PT [20]. For AP radiographs, the change in PT can only be indirectly observed by the variation of the area of the obturators [21].

Thus, the standing position and PT should be considered when measuring cup version to identify the effect of PT on version measurement and to assess the risk of adverse outcomes more accurately in THA patients during functional activities. The standing lateral (SL) radiograph may be an ideal method, in which both the cup version and PT can be assessed directly. However, the measurement method has not been studied yet. This study aimed to evaluate the reliability and validity of a method for measuring cup version on SL radiograph.

Material And Methods

3D simulation to investigate the relationship between incidence and cup version

SL radiography could be regarded as a variation of CL radiography, with the patients positioned from supine to standing, and the X-ray incidence adjusted from 45° to 90° (**Fig.1**). The main difference observed in the image was the projected shape of the cup rim caused by the change in the incident angle of the beam. Cup version on CL radiograph was measured between the vertical line of the film and the tangent line of the opening face of the acetabular cup [2]. The same method may be applied to SL radiograph, but it was necessary to identify whether the change in X-ray incidence significantly affects cup version measurement. However, it was impractical to perform multiple lateral radiographs with different X-ray incidences in patients considering the radiation exposure and ethical issues. In a previous study, a THA postoperative 3D model was built, in which some parameters, including the cup version, inclination, pelvic tilt, and incidence, were independently adjusted [20]. Independent variables and confounding factors were controlled using the standard physical model. Thus, in this study, standard 3D models were used to investigate the effect of incidence on cup version measurements.

This study recruited four healthy volunteers (two men and two women) without pelvic deformity who underwent surgery to perform a pelvic CT scan. The 3D pelvic models were built based on the pelvic CT data. Then, laser equipment was used to scan the titanium converge acetabular cups with a diameter of 48–52 mm (R3[◇] Acetabular System, Smith & Nephew, Inc., Memphis, Tennessee, USA) to establish the cup models. Finally, all postoperative models were created by integrating the cup model with the pelvic model. All 3D models were constructed using Geomagic Design X 2016.

In these 3D postoperative models, the actual versions and incidences can be independently set. Five groups of actual versions were set from 10° to 30°, at intervals of 5°. The X-ray incident angles were adjusted at intervals of 5° in the range of 45–90°. Measurements of five groups of actual versions using

the CL radiograph method described by Woo et al. [2] were performed on the 3D models under different groups of incidences (**Fig. 2**). The above measurements were repeated for the four postoperative 3D models.

Clinical validation of the SL radiograph method

Patients

Patients undergoing primary cementless THA between April 2020 and December 2020 were included in this study. Patients with a pelvic surgical history or spinal or pelvic deformity were excluded. In total, 87 consecutive patients were evaluated, including 43 men and 44 women with a mean age of 58.6 years (range, 19–84 years) and body mass index of 23.3 kg/m² (range, 15.8–33.3 kg/m²) at the time of the operation. The indications for THA were femoral head osteonecrosis in 37 hips (42.5%), osteoarthritis in 25 hips (28.7%), femoral neck fracture in 15 hips (17.2%), and others in 10 hips (11.5%). Four experienced orthopedic surgeons performed all operations using a posterolateral approach. All prostheses were selected from the R3[◇] Acetabular System and POLARSTEM[◇] Cementless Stem System (Smith & Nephew, Inc., Memphis, Tennessee, USA). The patient information was summarized in **Table 1**. This study was approved by the ethics committee of our institution, and informed consent was obtained from all participating patients.

Radiographs' acquisition

One week after THA, images including SL radiograph and CT scan were obtained to measure the acetabular component version. For a SL radiography, patients naturally stood with their feet together and were instructed to stand as still as possible. The radiation beam was centered over the greater trochanter and intersected the longitudinal axis of the body at a right angle. Imaging ranged from the upper edge of the sacrum to the lower edge of the stem (**Fig. 1b**). During the CT scan, the patients were in a supine position with the bilateral hip joints in a neutral position. All standardized radiographs and CT scans were performed by the same group of radiology technicians.

Measurement of version

Unlike the CL radiograph, the edge of the cup opening face was not clearly observed on the SL film to take the tangential line. We used the image processing system in our hospital to establish a circle through the outer edge of the cup. This circle intersected the elliptical arc of the cup opening face. The line of the two intersecting points was the long axis of the elliptical open face of the acetabular cup, which was similar to the tangential line of the cup opening face on the CL radiograph. The line is defined as the matching tangent line. The cup version on the standing radiograph was measured between the vertical line of the longitudinal axis of the body and the matching tangent line (**Fig. 3a**). All measurements were performed using an image-processing system in our hospital.

Assessment of reliability and accuracy

All measurements were performed by two observers who were blinded to the patients' information and the other observers' values. All images were randomly assigned to each observer by a research assistant who did not participate in the reliability assessment. Reliability refers to the consistency of the measurements. The intra-observer reliability of each method was assessed using the values measured by one examiner who performed the reassessment 4 weeks later. The inter-observer reliability of each method was assessed using the same two examiners.

Accuracy was defined as the proximity of the reference standard. CT scans was known as an accurate method to learn the true cup version [6]. However, variations of position had been proved to affect cup version by changing the PT [19, 22] and the supine position of CT scan was different from the standing lateral radiograph. Thus, we did not compare the radiographic measurements directly with the CT measurements. When measuring cup version in CT images, we adjusted the PT of CT images (**Fig. 3b**) matched with that measured on the SL radiograph (**Fig. 3a**). We then captured the sagittal plane through the center of the femoral head to show the actual version. Cup version was the angle between the line through the cup anterior and posterior edge and the horizontal line (**Fig. 3c**). Pelvic tilt measured in radiographs and CT images was based on the reported method: pelvic tilt was defined as the angle between a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory (**Fig. 3a, 3b**) [21].

Statistical analysis

In the 3D simulation analysis, the measurements of each group of versions at different incidences were evaluated using the two-way classification ANOVA. The intra- and inter-observer reliabilities of all measurements were calculated using the intraclass correlation coefficient (ICC) and 95% confidence interval (CI). The two-way random effects intraclass correlation model and absolute agreement were used to calculate the ICC; an ICC of 1 indicated perfect reliability, while an ICC of 0 indicated the opposite. To determine the convergent validity, version measurements of the radiographs and CT scans were compared using the paired t-test. The correlation between mean radiological and CT measurements was evaluated by Pearson's correlation coefficient (r). Correlation was characterized 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) [23]. Bland–Altman plots were presented to illustrate the difference between the methods. If the differences were within the 95% limits of agreement (95% LoA), the differences were clinically acceptable and the measurements of the two methods had good agreement. Statistical analyses were conducted using SPSS for Windows (version 25.0; SPSS Inc., Chicago, Illinois, USA), and statistical significance was set at $p < 0.05$.

Results

In 3D simulation, the version measurements of each group of actual versions under different incidences were shown in **Fig. 4**. No statistically significant differences of version measurements were observed between different groups of X-ray incidence ($p = 0.663$). All radiographic and CT measurements showed good consistency with ICCs >0.9 (**Table 2**). There was no significant difference (paired t-test, $p = 0.333$) in

mean version between radiographic measurements (15.56°; SD 11.22, -19.82° to 38.74°) and CT measurements (16.19°; SD 12.09, -23.00° to 47.20°). The correlation coefficient between mean radiographic and CT measurements was $r = 0.901$ ($p < 0.001$) (**Fig. 5**). Differences between the radiological and CT assessments were shown in Bland–Altman plots (**Fig.6**). The mean difference was -0.63° (SD 5.25°, -14.92° to 12.72°) and 79/87 (91%) of the differences were within the 95% limits of agreement.

Discussion

In this study, we focused on elucidating the accuracy and validity of the SL radiography for measuring the acetabular component version. Considering relatively high radiation dose and cost of CT scan, it is still essential to evaluate cup version without CT imaging in daily clinical practice. However, there is a concern that highly accurate X-ray photography may be required. CL radiographs as one of the most used method were shown debated accuracy and reliability in literatures [6, 10, 14, 24]. Several studies had confirmed that the cup version was moved either into or out of the safe zone from the supine to standing position [19, 25, 26], meaning that the cup position assessed on supine CL radiograph does not seem to reflect the postoperative functional position of standing. Hence, the development of a new method for assessing the cup version in the standing position is warranted. This study is the first to investigate the validity and accuracy of SL radiographs in the evaluation of the cup version.

3D simulation analysis results showed no significant effect of X-ray incidence on version measurement on lateral radiographs. We proposed a measuring method on SL radiograph: version was measured between the horizontal line and the tangent line of the cup opening face. The tangential line was determined through two intersecting points of the cup outer edge circle and the opening face elliptical arc. Cup version measurement were performed on SL radiographs and CT scans from 87 patients after THA to evaluate the reliability and accuracy of SL radiographs. We found that no significant difference in mean version between radiographic measurements and CT measurements (paired t-test, $p = 0.333$). The radiographic versions were well correlated to the CT versions ($r = 0.901$, $p < 0.001$) and 91% of the differences were within the 95% limits of agreement, indicating good agreement between the measurements of SL radiographs and CT scan.

There are currently few varieties of lateral radiograph methods to measure cup version being introduced in the literature. The best-known method was introduced by Woo et al. based on the CL radiograph [2]. Nunley et al. [14] found a strong correlation ($p = 0.82$, $p < 0.001$) between version from CT scans and serial CL images, but the variations of CL films were exceeded 10° for 20% of patients. They concluded that CL radiographs were limited for the precise analysis of acetabular cup version. Peter et al. [15] showed that the version measured on CL radiograph was highly correlated with CT scan ($p=0.804$, $p<0.01$). They believed that the CL radiograph was a useful substitute for CT scans when assessing the supine version after THA. It has been reported that the change of PT affected the cup version considerably from supine to standing position [16-19]. The debated results regarding the accuracy of CL radiograph may be due to the effect of PT. More importantly, the cup position assessed on supine CL

radiograph does not seem to reflect the postoperative functional position of standing. The traditional “safe zone” theory seemed no applicable to standing or sitting functional position. That’s why we stress the cup version evaluation on standing lateral radiograph. What’ more, to reduce the error caused by pelvic tilt and uniform the reference plane, we further adjusted the PT of CT scan consistent with that of the SL radiograph to verify the agreement between SL radiograph and CT. Our results showed a positive correlation ($r = 0.901$, $p < 0.001$) between radiographic versions and PT-adjusted CT versions, which were non-inferior to the Nunley’s and Peter’s results. Furthermore, the differences were almost within the 95% limits of agreement, indicating good agreement and clinically acceptable error between the measurements of SL radiographs and CT scan.

Similar to our study, McCollum et al. [27] evaluated the cup version on a true lateral radiograph based on an imaging method like CL radiograph. The patient stood on the operated hip with the uninvolved hip flexed to 90°. The X-ray tube was angled upward to 30°, and the beam was centered on the acetabulum. They found a smaller variation (within 10°) on the SL measurements than that of the CL radiograph (20°). Unfortunately, they did not further evaluate the accuracy of this method compared with CT. Patients are inevitably needed to flex the uninvolved hip joint, which can result in variations in PT and produce errors in the measurement. In this study, patients were required to stand naturally, and the films were easily obtained. Furthermore, the reliability and accuracy of SL radiograph were evaluated by comparing with CT.

There are some limitations to this study. We developed a method to measure cup version on SL radiograph and demonstrated that it was accurate and reliable for clinical evaluation. But the measurement consisted of several sequential steps so it still not efficient enough. Further development of software may be needed to automate and streamline the measurement procedure for generalization. Also, measurement variations would be found in individual patients with large cup abduction angle (>50°) or pelvic obliquity. Because the lateral projection of the cup opening face on the radiograph was close to a circle, making it difficult to identify the longest axis of the opening face for the measurement. Thus, appropriate cup abduction angle and correction of pelvic obliquity were need for better precision and reliability of SL radiograph.

Conclusions

SL radiograph has advantages in assessing functional acetabular cup anteversion and identifying the PT simultaneously, with acceptable accuracy and reliability. SL radiograph is recommended for the evaluation of cup version after THA.

Abbreviations

Standing lateral (SL); cross-table lateral (CL); computed tomography (CT); total hip arthroplasty (THA); intraclass correlation coefficient (ICC); confidence interval (CI); pelvic tilt (PT)

Declarations

Ethics approval and consent to participate

All experimental procedures were approved by the ethical committee of Sun Yat-sen Memorial Hospital of Sun Yat-sen University. All volunteers included in the study provided written informed consent.

Consent for publication

The author confirms:

- that the work described has not been published before;
- that it is not under consideration for publication elsewhere;
- that its publication has been approved by all co-authors;
- that its publication has been approved (tacitly or explicitly) by the responsible authorities at the institution where the work is carried out.

Availability of data and materials

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

Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Authors' contributions

All listed authors meet the criteria for authorship and have contributed to the study design, data generation, data analysis, manuscript writing and manuscript review.

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Tables

Table 1 The demographics of the patients (n = 87)

Parameters	Value of number
Age (years) (range)	58.6 (19 to 84)
Gender (male/female)	43 / 44
BMI (kg/m ²) (range)	23.3 (15.8 to 33.3)
Operated side (left/right)	41 / 46
Preoperative diagnosis (n, %)	
Femoral head osteonecrosis	37 (42.5)
Osteoarthritis	25 (28.7)
Femoral neck fracture	15 (17.2)
Others	10 (11.5)
Type of prosthesis (n, %)	
R3 [◇] Acetabular cup (Smith & Nephew)	87 (100)
POLARSTEM [◇] cementless stem (Smith & Nephew)	87 (100)

BMI, Body mass index

Table 2. Intra- and interobserver reliability of each measurement

	Intra-observer reliability		Inter-observer reliability	
	ICC	95% CI	ICC	95% CI
Radiograph	0.957	0.932 to 0.968	0.973	0.956 to 0.992
CT scan	0.943	0.911 to 0.956	0.968	0.957 to 0.989

(ICC, intraclass correlation coefficient; CI, confidence interval)

Figures

Figure 1

Radiographic method of cross-table lateral radiography and standing lateral radiography. (1a) Cross-table lateral radiography: patients were positioned supine with the uninjured hip flexed to 90° and the X-ray incidence angle was 45°. (1b) Standing lateral radiography: patients naturally stood with their feet together and the radiation beam was centered over the greater trochanter with the X-ray incidence of 90°.

Figure 2

Cup version measurements under different incidences on the 3D model. Ten groups of X-ray incidences were set from 45° to 90° at intervals of 5°. Five groups of actual versions were set from 10° to 30° at intervals of 5°. Different groups of cup versions were measured under different X-ray incidences.

Figure 3

Measurement methods of cup version on radiograph and CT scan. (3a) Measuring method of cup version on a SL radiograph. Version was measured between the vertical line of the body longitudinal axis and the tangent line. The tangential line of the cup opening face was determined through two intersecting points of the cup outer edge circle and the opening face elliptical arc. (3b) Pelvic tilt was adjusted to the value of radiograph before cup version measurement in CT image. Pelvic tilt was defined as the angle between a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory. (3c) Cup version measurement in CT image after PT adjustment. Cup version was the angle between the line through the cup anterior and posterior edge and the horizontal line.

Figure 4

The measurement results of different actual versions under different X-ray incidences. No statistically significant differences of version measurements were observed between different groups of X-ray incidence ($p = 0.663$).

Figure 5

Scatter plot of mean radiographic and CT measurements with the correlation slope. The correlation coefficient between mean radiographic and CT measurements was $r = 0.901$ ($p < 0.001$).

Figure 6

Bland-Altman graph showing differences between mean radiographic and CT measurements of cup version. The straight line represents the mean difference of measurements, and the dashed lines represent the 95% limits of agreement (mean +/- 1.96 SD).